INVESTING FOR THE FUTURE

ANNUAL REPORT 1990-1991

REPORT OF THE AGRICULTURAL AND FOOD RESEARCH COUNCIL

To the Secretary of State for Education and Science

The Agricultural and Food Research Council, as required by Schedule 1 of the Science and Technology Act, 1965, submits the following report on its activities during the period from 1 April 1990 to 31 March 1991.

Mr M A Grant, Chairman
Professor T L Blundell FRS, Director General

Laid before Parliament pursuant to Schedule 1 of the Science and Technology Act, 1965.

19 November 1991.

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Members on the occasion of the Council meeting, April 1991, at the Royal Society, Carlton House Terrace, London.

MEMBERS OF COUNCIL
at 31 March 1991

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*Deputy Chairman and Secretary**

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O Rees CB
Welsh Office

Sir Mark Richmond FRS
SERC

Professor H Smith FRS
Royal Society

* The title of Secretary is now replaced by that of Director General

CHAIRMAN'S STATEMENT

1990/91 has been an exciting and satisfying year for AFRC, at the end of which we are able to look forward to greater stability in our funding and in our new institute structures.

Alistair Grant

Chairman

There are many signs of the vitality and confidence which have played such an important part in seeing AFRC through the severe manpower cuts of recent years, and in the re-shaping of our research base for the scientific demands of the coming decades. Particularly important have been the continuing international and national recognition of our scientific excellence in key areas of the biological and related sciences; our increased participation in pan-European and other international programmes, and in collaborative initiatives with the other UK Research Councils; a doubling of our income from industry over the past five years; and our successful establishment of coordinated programmes across institutes, universities and polytechnics.

None of these achievements would have been possible without the dedication of AFRC's staff. Their commitment and determination have impressed me enormously as I have visited the Institutes of the Council and its Central Office.

The theme of this year's Report "Investing for the Future" is an explicit statement of how we see our role in meeting and capitalising upon the scientific challenges and opportunities that face us, and their fundamental and long term importance to the agricultural, food and other biologically based industries of this country. Without vision the people perish, says the proverb - it is equally true of scientific endeavours and of industries.

But the vision must be shared and promulgated. The growing industrial reliance on biologically based technologies and information technology makes AFRC's role even more relevant. A lowering of tariff barriers, decreases in subsidies, changing patterns of consumer demand, and changes in the economic and meteorological climates will influence our agricultural and food industries in ways at first glance far removed from fundamental and strategic research, but in which AFRC science has a major contribution to make if efficiency is to be maintained and improved.

We shall be working to ensure that confidence in our own science continues to translate into stronger and closer links with our industries and interest groups - with the farming community and its advisers, with the agrochemical sector, biotechnology companies, the food industry, consumer groups and those interested in environmental issues.

AF

PiGMaP

. . . AFRC scientists are coordinating a ECU1.2M three-year project to map the pig genome.

CLIMATE

. . . AFRC has expanded its research programmes on biological responses to global environmental change.

BSE

. . . A new £9M four-year coordinated programme on the biology of the spongiform encephalopathies has been launched with awards to seven universities and the AFRC Institute for Animal Health.

COLLABORATION

. . . "Clean Technology" is a new joint programme with the SERC.
. . . AFRC has joined the Biotechnology Joint Advisory Board.

STEM CELLS

. . . Embryonic stem cell lines have been established from domestic livestock - offering important prospects for advances in mammalian biology.

SELECTION

. . . Major break throughs in under-standing the genetic regulation of flowering suggest it might be possible to control the quantity, timing and position of flowers.

BACTERIA

. . . A new nucleic acid technology is revolutionising bacterial classification and identification - it has potential for emerging pathogens.

INTERNATIONAL

. . . A five-year Memorandum of Understanding has been signed with the Directorate of Agricultural Research of the Dutch Ministry of Agriculture.

. . . Scientific exchange visits have commenced with Spain, Germany, and the Netherlands. The first joint fellowships with INRA (France) have been awarded. New initiatives have commenced with Japan, and Australia and New Zealand.

FINANCE

. . . Restructuring of the Institute of Plant Science Research was completed and rapid progress made in the provision of new laboratories and facilities for three other institutes. One major site and two farms have been sold to help fund this restructuring programme.

STUDENTS

. . . AFRC has completed a three-year programme to increase the number of research studentships awarded - over 130 extra awards will have been made by the 1991/92 academic year.

STAFF

. . . New career development arrangements for staff of exceptional ability and potential have been agreed.

INDUSTRY

. . . AFRC's commitment to the Government's LINK programme of collaborative public sector/industry research projects has topped £4M. AFRC has invested a further £2.4M in its own "Collaboration with Industry Scheme".

FRANCAIS *Un récapitulatif de l'exercice 1990-1991*

ETUDIANTS . . . Un programme sur trois ans, qui a augmenté de 130 le nombre de postes d'étudiants de recherche offerts avant la fin de l'année universitaire 1991/92, s'est terminé.

INTERNATIONAL . . . Un accord pour cinq ans a été signé avec la Direction de la recherche agricole du Ministère néerlandais de l'agriculture.

. . . Des visites d'échanges scientifiques ont été lancées avec l'Espagne, l'Allemagne et le Pays-Bas. Les premières bourses d'études financées conjointement avec l'INRA (France) ont été octroyées. De nouvelles initiatives ont été prises avec le Japon, l'Australie et la Nouvelle-Zélande.

COLLABORATION . . . Un nouveau programme conjoint a été lancé avec le SERC sous le titre de "technologie propre".

. . . L'AFRC est devenu membre du Conseil consultatif national de biotechnologie.

FINANCES . . . La restructuration des instituts de recherche botanique a été menée à bien et des progrès rapides ont été réalisés dans la création de nouveaux laboratoires et installations connexes pour trois autres instituts. Un terrain important et deux fermes ont été vendus afin de contribuer au financement de ce programme de restructuration.

PERSONNEL . . . De nouvelles dispositions de développement professionnel ont été convenues en faveur de membres du personnel ayant fait preuve d'aptitudes et de promesses exceptionnelles.

INDUSTRIE . . . L'AFRC a engagé plus de £4M dans des projets figurant au programme gouvernemental LINK de collaboration de recherche entre le secteur public et l'industrie. L'AFRC a consacré £2,4M supplémentaires à son propre programme de collaboration avec l'industrie.

BSE . . . Un nouveau programme coordonné de £9M sur la biologie des encéphalopathies spongiformes a été lancé et s'est traduit par l'octroi de concours à sept universités ainsi qu'à l'Institut de santé animale AFRC.

PiGMaP . . . Les chercheurs de l'AFRC ont entrepris de coordonner un programme triennal de ECU 1,2M pour établir la carte du génome des porcins.

SÉLECTION . . . D'importantes percées dans la compréhension de la régulation de la floraison donnent à penser qu'on pourra contrôler l'ampleur, le timing et la position des floraisons.

CELLULES SOUCHE . . . Des lignées de cellules souche embryonnaires ont été établies pour le cheptel, présentant d'importantes perpectives de progrès en biologie des mammifères.

BACTÉRIES . . . Une nouvelle technologie des acides nucléiques est en train de révolutionner la classification et l'identification des bactéries, et présente d'intéressantes possibilités pour la lutte contre les pathogènes émergeants.

CLIMAT . . . l'AFRC étendu ses travaux dans le domaine des réponses biologiques face aux évolutions de l'environnement.

DEUTCH *Zusammenfassung des Jahres 1990-1991*

STUDENTEN . . . AFRC hat ein Dreijahresprogramm zu Ende gebracht, dessen Ziel es war, die Anzahl der Forschungsstipendien zu erhöhen - für das akademische Jahr 1991/92 werden mehr als 130 Stipendien zusätzlich gewährt.

INTERNATIONALE BEZIEHUNGEN . . . Ein Fünfjahresabkommen wurde mit der Abteilung Landwirtschaftsforschung des Landwirtschafts-ministeriums der Niederländen geschlossen.

. . . Ein Austauschprogramm fur Wissenschaftler wurde mit Spanien, Deutschland und den Niederlanden begonnen. Zusammen mit INRA (Frankreich) wurden die ersten gemeinsamen Forschungsstipendien gewährt. Neue Initiativen wurden mit Japan, Australien und Neuseeland eingeleitet.

ZUSAMMENARBEIT . . . "Saubere Technologien" ist ein neues, mit SERC gemeinsam gestartetes Programm.

. . . AFRC wurde Mitglied des Biotechnology Joint Advisory Board.

FINANZEN . . . Die Umstrukturierumg des Instituts für Plant Science Research wurde vollendet; neue Laboratorien und Einrichtungen werden für drei weitere Institute zügig bereitgestellt. Zur Finanzierung dieses Struktur programms wurden ein größeres Grundstück und zwei Farmen verkauft.

BELEGSCHAFT . . . Es sind neue Beförderung-smöglichkeiten für besonders fähige und tüchtige Mitarbeiter geschaffen worden.

INDUSTRIE . . . Der Anteil von AFRC am LINK-Programm der Regierung für gemeinsame Forschungsprojekte der Öffentlichen Hand und der Industrie hat 4 Mio. £ über-schritten. Weitere 2,4 Mio £ hat AFRC in den eigenen "Plan für Zusammen-arbeit mit der Industrie" investiert.

BSE . . . Ein neues, koordiniertes Vierjahres programm mit einem Umfang von 9 Mio £ zur Erforschung der Biologie der spongiformen Encephalo-pathie wurde gestartet, mit Stipendien an sieben Universitäten und das AFRC-Institut für Tiergesundheit.

PiGMaP . . . AFRC-Wissenschaflter koordinieren ein Dreijahresprojekt mit einem Umfang von 1,2 Mio ECU zur Genomkartierung bei Schweinen.

ZUCHTAUSWAHL . . . Größere Durchbrüche im Verständnis der genetischen Regelung der Blüte legen den Schluß nahe, daß Menge, Zeitpunkt und Anordnung von Blüten gesteuert werden könnten.

STAMMZELLEN . . . Embryo-Stammzellinien wurden von Haustieren aufgebaut - mit bedeutenden Aussichten auf Fortschritte in der Säugetierbiologie.

BAKTERIEN . . . Eine neue Nukleinsäure-Technologie revolutioniert die Klassifikation und Identifikation von Bakterien - mit großen Möglich-keiten für die Erkennung von Pathogenen.

KLIMA . . . Wir haben unsere Erforschung biologischer Reaktionen auf globale Umweltveränderungen ausgedehnt.

ESPANOL *Resumen del año 1990-1991*

ESTUDIANTES . . . El AFRC ha dado fin a un programa de tres años para aumentar el número de concesiones de becas para investigación: más de 130 becas suple-mentarias se habrán hecho para el curso académico de 1991-92.

INTERNACIONAL . . . Se ha firmado una Acta de Convenio quinquenal con la Dirección de Investi-gaciones Agrícolas del Ministerio de Agricultura de Holanda.

. . . Han comenzado las visitas de intercambio científico con España, Alemania y Holanda. La primeras coleg-iaturas conjuntas con la INRA de Francia también se han concedido. Se ha dado curso a nuevas iniciativas con Japan, Australia y Nueva Zelanda.

COLABORACION . . . La "Tecnología Limpia" es un nuevo programa conjunto con la

SERC . . . El AFRC ha entrado a formar parte de la Junta Consultora Conjunta de Biotecnología.

ECONOMIA . . . Se ha dado fin a la reestructuración de los Institutos de Investigación Científica de Instalaciones, haciéndose rápidos progresos en el establecimiento de nuevos laboratorios e instalaciones para otros tres institutos. Se han vendido dos granjas y un gran terreno para obtener fondos a invertir en este programa de reestructuración.

PERSONAL . . . Se han tomado medidas conducentes al desarrollo de nuevas carreras para miembros del per-sonal dotados de capacidad y potencial excepcionales.

INDUSTRIA . . . El compromiso del AFRC con el programa gubernamental LINK destinado a proyectos en colaboración de los sectores público e industrial han requerido 4 millones de libras esterlinas. El AFRC ha invertido otros 2,4 millones de libras en su propio "Plan de Colaborción con la Industria".

BSE . . . Se ha lanzado un nuevo programa coordinado que consuirá 9 millones de libra esterlinas durante sus cuatro años de duración, dedicado a la biologia de las encefalopatías espongiformes, con concesiones eco-nómicas a siete universidades y al Instituto e Salud Animal del AFRC.

MAPA PORCINO . . . Científicos del AFRC están coordinando un proyecto de 1,2 millones de ECUS y tres años de duración para obtener el gráfico de la conform-ación del genoma del cerdo.

SELECCION . . . Importantes descubrimientos en el entendimiento de la regulación genética de la floración sugieren que podría ser posible controlar la cantidad, época y posición de las flores en las plantas.

GÉNESIS CELULAR . . . Se han descubierto líneas genéticas celulares en los embriones de animales domésticos, lo que ofrece perspectivas importantes para los adelanto en la biología de lo mamíferos.

BACTERIAS . . . Una nueva tecnología referente al ácido nucleico está revolucionando las tares de clasificación e identificación bacteriológicas: ofrece potencial frente a la aparición de agentes patógenos.

CLIMA . . . Hemos ampliado nuestras investigaciones sobre las reacciones biológicas a los cambios mund-iales en el medio ambiente.

DIRECTOR GENERAL'S REPORT

It was my good fortune to be appointed at the end of a period of radical change in the AFRC. During this time research priorities have moved away from increased output, a legacy of the post-war emphasis on feeding the nation. They now focus on research underpinning the efficiency and competitiveness of our agricultural and food industries. Our research has become more fundamental and strategic, less close to application; it creates options for our industries rather than products for sale. Our priorities also address issues of public concern about animal welfare, food quality and safety, and the farm environment.

These changes have been traumatic; they might have been catastrophic if they had not coincided with the most exciting period in the history of biology. There are now new opportunities in molecular biology, genetics and immunology that are applicable not only to most crops and livestock, but also to biological-based industries outside recent agricultural practice. So in 1991 the new scientific opportunities, and hopefully a period of financial stability, create optimism and confidence for the AFRC; we can focus on *investing for the future*, the theme of this year's Annual Report.

On my appointment in January 1991, I took time to talk with scientists and support staff throughout the Council. In the first few months I was able to visit all seven AFRC institutes. I also visited several of the Scottish Agricultural Research Institutes and talked with many from academia, industry and Government with interests in the AFRC. These stimulating discussions confirmed my earlier impression gained as a Council Member over the previous five years: we have been quick to exploit the new opportunities, both in our institutes and in our university funded groups. Now the first priority of AFRC is to maintain the excellence of our research and to expand it. This has been acknowledged under the imaginative leadership of my predecessor, Professor Bill Stewart FRS, who has done much to reinvigorate fundamental and strategic research in our Council. He, together with Dr Brian Jamieson, who was Director of Central Office throughout the period and also Acting Secretary from October 1990 until the end of the year, established the AFRC as an efficiently run Council with great strengths in the non-medical biological sciences. It is a genuine pleasure to record my thanks and that of Council for their efforts and achievements in guiding and promoting AFRC's development through what has continued to be a period of continuing exciting challenges.

New biological science

For me the excitement in research comes when the new knowledge of molecular structure and genetics is applied to whole plants or animals. AFRC research provides many examples of such advances. Amongst the most fundamental are the genome mapping studies of farm animals and plants. As described on page 23 there are two types of map: the physical map that tells us where genes are located on the chromosomes and the genetic map which tells us how different genes are linked or inherited together. Farm animal genome maps, like PiGMaP, can provide markers of valuable traits for breeding and for disease susceptibility. The plant maps will also be valuable for breeders, but much initial work will be carried out on a weed, *Arabidopsis thaliana*, which has a particularly simple genome. But if we can identify key genes in "the weed", it should be straightforward to find their equivalents in crops. This may offer the possibility of genetically engineering plants with traits from other species or even engineering the natural gene products using a knowledge of the protein molecular structure. Much is to

Collaboration with other Research Councils

AFRC participates fully in collaborative programmes with other Research Councils. These include:

- **Clean Technology (with SERC)**
- **Pollutant Transport in Soils and Rocks (with NERC)**
- **Metal Ions in Biology and their Coordination Chemistry (with SERC)**
- **Biochemistry of Metabolic Regulation in Plants (with SERC)**
- **Joint Agriculture and Environment Programme (with ESRC and NERC)**

AFRC continues to enjoy a close working relationship with the MRC particularly in the areas of nutrition, and the spongiform encephalopathies.

In 1990, AFRC became a full member of BJAB (the Biotechnology Joint Advisory Board), initially formed to draw together the biotechnology interests of SERC and DTI.

Cooperation and liaison between the Research Councils has been further enhanced by the move in April 1991 of the AFRC's Central Office to the Polaris House site, Swindon.

be learnt from the human and mouse mapping programmes which are quite far advanced; cooperation with the MRC, Imperial Cancer Research Fund and other medical research organisations will be important here. All such genome mapping projects are international, involving collaborators with complementary expertise and interests working in coordinated programmes.

Fundamental advances at the cellular level are also important; there is no better example than the work on stem cells which has much to teach us about tissue differentiation but may also be useful in animal breeding as a means of selecting particular genetic traits. Stem cell technology is already being used to develop animal models of disease, to explore differentiation of blood cells and cells of the immune system, and to investigate the role of PrP protein in spongiform encephalopathies.

Transferring technology

Developments in molecular and cell biology, and in the engineering and information sciences, offer real possibilities for greater efficiency in agriculture, food manufacture and other industries. This Report describes advances in fundamental research that have led to new technologies, ready for transfer to our agricultural, food and other biologically based industries. Many of these advances have been incorporated into new Government LINK programmes, as can be seen on page 56, where we list the eight LINK programmes with AFRC involvement. They include not only molecular projects such as protein engineering, where a fundamental understanding of the structure and function allows protein redesign to meet industrial specifications, but also projects such as the industrial uses of crops, where manipulation of plant genomes offers particularly exciting opportunities for production of antibiotics, new oils for combustion and the chemical industry and other non-food products. Such new possibilities have been the subject of considerable attention throughout Europe. Although the science is recognised as state-of-the-art and the scientific objectives are realistic, we are very often told by industrialists that the new ventures will not be economically competitive. But I wonder how often this reflects vested interests in industrial plant that would be inappropriate to the new products. In years past Britain's land was used to a much larger extent for the renewable production of energy, construction materials, fibres and pharmaceuticals. It is possible that our new research will allow a return to such an attractive scenario.

Global environmental change

In recent years attention has focused on global environmental change. Because approximately 80% of land in the United Kingdom is farmland, the nature of agricultural production is important to these changes. For example, water or nitrogen movement between land and atmosphere can be changed appreciably when there are switches between crops that have different annual cycles, or which are different in the surface roughness they create. Existing meteorological models do not take into account dynamic changes of vegetation structure. However, in the AFRC there is a wealth of expertise available in areas such as leaf development and abscission and water transport into roots and through plants, that will need to be considered in the more sophisticated models of the future.

Understanding the physiological and biochemical consequences of environmental changes is essential if we are to be able to develop sound strategies for agriculture and food production in the future. Increased levels of greenhouse gases and the consequent warming will vary from place to place in their impact on the growth, health and quality of both natural and farmed biological communities. Although we have considerable knowledge gathered under current climatic and atmospheric conditions, we are substantially ignorant of the consequences for plants of elevated CO_2 levels. We also have little information on how soil microbial processes will be altered by climate change and the impact of these on nutrient availability, microbe/plant interaction and crop growth. We need to understand these impacts and to define desirable traits at the level of the molecule, plant or animal, community and production system to enable new cropping and uses to be developed.

As we report on page 48, we are complementing our considerable programme of underpinning research relating to biological responses to global environment change, with a new mini-programme in universities and polytechnics of £1M over three years to study the effects of enhanced carbon dioxide levels on crop plants. We are launching joint programmes with NERC on the effects of climate change on the natural and farmland environments. The Councils will take a complementary approach. The new programme will focus on understanding how plants and animals react to stresses invoked not only by changes in temperature, water, nutrients and salinity, but also by new pests and diseases. The work will be not only relevant for Europe but also for developing countries and tropical rain forests.

The impact of global climate change is inherently an international issue. AFRC participated in a seminar in Tokyo precisely on this topic; and many of the scientific priorities identified in our two Memoranda of Understanding, with the Dienst Landbouwkundig Onderzoek (DLO), the Netherlands and with the Institut National de la Recherche Agronomique (INRA) France, are directly relevant.

The national debate

The AFRC continues to contribute to debate about the organisation and funding of science. We have contributed to the Royal Society enquiry into the state of British science, which has focused on scientific structures and organisations. The mixed economy of AFRC institutes on the one hand, and units and project grants at universities and polytechnics on the other, provides a good model of UK science as a whole. The two types of scientific institution complement each other, and their close interaction, provided by AFRC Link groups and other collaborations, provides access for all to the spectrum of facilities offered by each.

Funding

Financial pressures, particularly higher than expected inflation, superannuation and staff restructuring costs have put our funds under considerable pressure. Although our total expenditure increased from £130M in 1989/90 to £141M in 1990/91, this reflected a large increase in capital expenditure on land and buildings as part of restructuring. Superannuation is a special problem for the AFRC. The costs were £7.8M in 1985; they rose to £13.9M in 1990/91; and they are forecast to increase to £23M in 1996/97. We are requesting help from the ABRC on this serious matter. Council is also facing a number of unforeseen and inescapable demands for capital expenditure to meet new statutory requirements and exceptional expenditure on security. In particular regulations have been made under the Animals (Scientific Procedures) Act 1986, the Health and Safety at Work Act 1974 and the Environmental Protection Act 1990.

Unfortunately the Treasury index used by Government does not reflect the increasing costs in activities like research. In AFRC this has contributed to a further 380 redundancies in 1990/91 together with a sharp and most undesirable cut in our expenditure on capital equipment in institutes and a decrease in real terms for research grants to universities and polytechnics.

AFRC and Parliament

During the period of this Report AFRC presented evidence to Parliamentary Committees on a wide range of issues.

House of Lords Select Committee on Science and Technology: Sub Committee I - Innovation in Manufacturing Industry (April 1990)

House of Commons Select Committee on Agriculture: Inquiry into Bovine Spongiform Encephalopathy (June 1990)

House of Lords Select Committee on Science and Technology: Sub Committee II - Enquiry into International Scientific Programmes (July 1990)

House of Lords Select Committee on the European Communities: Sub Committee D - Non Food Use of Agricultural Production (July 1990 - written, October 1990 - oral)

House of Lords European Communities Committee: Sub Committee F (Environment): Enquiry into Municipal Waste Water Treatment (February 1991)

House of Lords Select Committee on Science and Technology: Science Budget 1991-92 (February 1991)

House of Lords European Communities Committee D (Agriculture & Food): Future of the CAP (March 1991)

Research and training in HEIs

Last year's Report expressed AFRC's sensitivity to the difficulties experienced by HEIs in attracting and retaining the most able scientists in research careers, and it outlined our proposals for enhancing career development and stability. Whilst not exaggerating the scale of our achievements, very significant progress has been made and is reported on page 56. For example, as well as completing to target our three year plan of increasing the number of research studentship awards by about 40 a year, we have increased the post-graduate stipend.

At the end of 1990 we awarded the first five AFRC postdoctoral fellowships. These five-year awards are intended to help retain and attract back from overseas able researchers by allowing them to devote a significant period to full time research. The first AFRC Research Professorship has been awarded to Professor Brian Follett FRS (University of Bristol).

Our funding for responsive mode grants to the universities and polytechnics provides a mechanism for developing promising new lines of research and supporting new ideas bubbling up from the scientific community. It also complements the Council's large coordinated programmes in specific areas of research. However, because total Government funding of AFRC has been decreased in real terms whereas applications have become more numerous, we have unfortunately been unable to maintain support for alpha-rated grants at the level we would have wished. We have already announced our intention of restoring the percentage of alpha grants funded to the 1988/89 level, and at the end of the period under

review additional funding was sought and gained from within the ABRC Flexibility Margin.

Council management and structures

The changes in the emphasis of our research have been accompanied by radical restructuring: the 28 research centres that existed ten years ago in the AFRC have been reorganised into seven institutes on eleven sites. There have been decreases in permanent staff to less than 50% of the total in 1983, and an increase in proportion of staff on short, fixed-term appointments. There has been a move from long term funding by Government Departments towards short term open contracting. At the same time we fund an increasing proportion of research at the universities.

These trends have made a reconsideration of Council structures an important issue in the past year. Are the structures that have served us well in this period of radical structural change appropriate to the challenges of the 1990s when we hope to carry out imaginative new science in a period of greater financial stability? Are Council structures appropriate to the mix of basic and strategic science funded through the Science Base and the strategic and applied research funded by Government Departments in support of policy or for the "public good"?

In making recommendations for new Council structures, I am particularly aware that virtually all advances in science derive from researchers who begin by pursuing a scientific paradigm but are either confronted by an anomaly or attracted by an analogy with another research area. Science is not a linear process and it cannot be totally forward planned. By definition truly innovative research produces unpredicted conclusions. Management can plan for the paradigm but monitoring and evaluation must allow for flexibility in objectives if they are to encourage real scientific innovation. This is true for applied as well as basic and strategic research.

With respect to the research funded through the Science Base (DES funds), the role of management in the AFRC is to define strategic and applied areas of biological and engineering science that are relevant to the health of agriculture, food and other biological-based industries in the United Kingdom. This is top-down planning. The detailed science within the strategic or applied areas must be defined by active scientists; a bottom-up process. Council structures should facilitate a proper balance between the two. But the excitement of bench and field science should pervade the whole organisation.

In order to achieve these objectives I have recommended, and Council has accepted, changes to Council structures which bring more scientific expertise into our strategic planning and at the same time streamline our management. Although the implementation of these changes will commence outside the period reviewed in this Report, their importance is such that it is imperative not to delay their announcement until Autumn 1992. Briefly they are as follows.

We have decided not to appoint a Deputy Secretary. The funds will be used to employ three part-time Senior Scientific Consultants. The Consultants will be Professor John Krebs FRS, of Oxford University, Professor Don Boulter CBE of Durham University and Professor Roger Whittenbury of Warwick University. They will represent the University/Polytechnic interests on the Strategy Board (see below); they will participate in an informal science policy "think-tank" and they will produce "position papers" on <u>scientific</u> policies that cross disciplines, underpin coordinated programmes and/or impinge upon socio-economic policies. The position papers would provide a contribution to policy in the Science and Policy Divisions, and a basis for discussion in Strategy Board and Research Committees.

A new part-time Director of Science will make a leading contribution to the development of scientific policy. Professor Brian Heap FRS will act in this capacity, initially on a temporary basis. The responsibilities include participation in think-tank discussions and Council representation of some broad issues such as bioethics, animal welfare and biotechnology. The coordination of the administration will be through the Director of Administration, Dr Brian Jamieson, who will continue to have responsibility for Central Office.

The title of Secretary of AFRC is replaced by that of Director General, reflecting the role as chief executive and coordinator of the Directors of Science, Research and Administration. Management Board and Strategy Committee will be reconstituted as a Strategy Board with the Director General as Chairman and the Director of Science as Deputy Chairman. The Strategy Board will include the Directors of Research and Administration, the Chairmen of the three Research Committees and the Senior Scientific Consultants. A Scottish Office representative is assessor. The Strategy Board will meet eight times per year, at times appropriate to our annual corporate planning process and Council discussions.

These changes are evolutionary rather than revolutionary; gradual rather than radical changes were required. None of the changes decreases the overall responsibility of Council for the scientific direction and management of the AFRC. Indeed the changes should improve the presentation of issues to Council and increase the opportunities for lively and constructive debate.

"... the first priority of AFRC is to maintain the excellence of our research .."

FRONTIERS IN THE *Biological Sciences*

10-11 *Embryonic stem cells - the "all purpose" cells*

12-13 *Bacterial family trees and tell-tale signatures*

14-15 *Maintaining early pregnancy in cattle*

16-17 *Controlling cross-membrane traffic*

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20-21 *Studying the immune response - as it happens*

22-24 *Advances in gene identification and mapping*

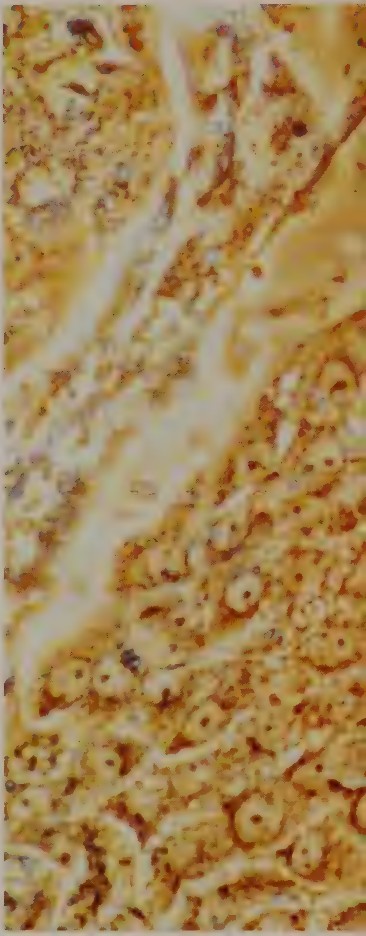
EMBRYONIC STEM CELLS – THE "ALL PURPOSE" CELLS

Embryonic stem cells are unspecialised cells which have the potential to differentiate into specific adult cell types. What makes them particularly interesting is that they can be grown and genetically manipulated in vitro *and re–introduced into an embryo where they participate in the development of a chimaeric but otherwise normal animal. Of particular importance is their ability to make viable gametes. Thus they have a three–fold importance: i) they allow analysis of the cellular and molecular processes governing cell and tissue differentiation; ii) they provide an ideal system for studying the regulation and activity of individual genes; and iii) they offer a way of circumventing the limitations of traditional animal breeding in selecting for specific genetic traits. AFRC has major programmes on the basic biology of stem cells. This report focuses on animal cell systems, however research is also in progress on plant stem cells.*

Precision injection of DNA allows genes to be introduced into unspecialised cells.

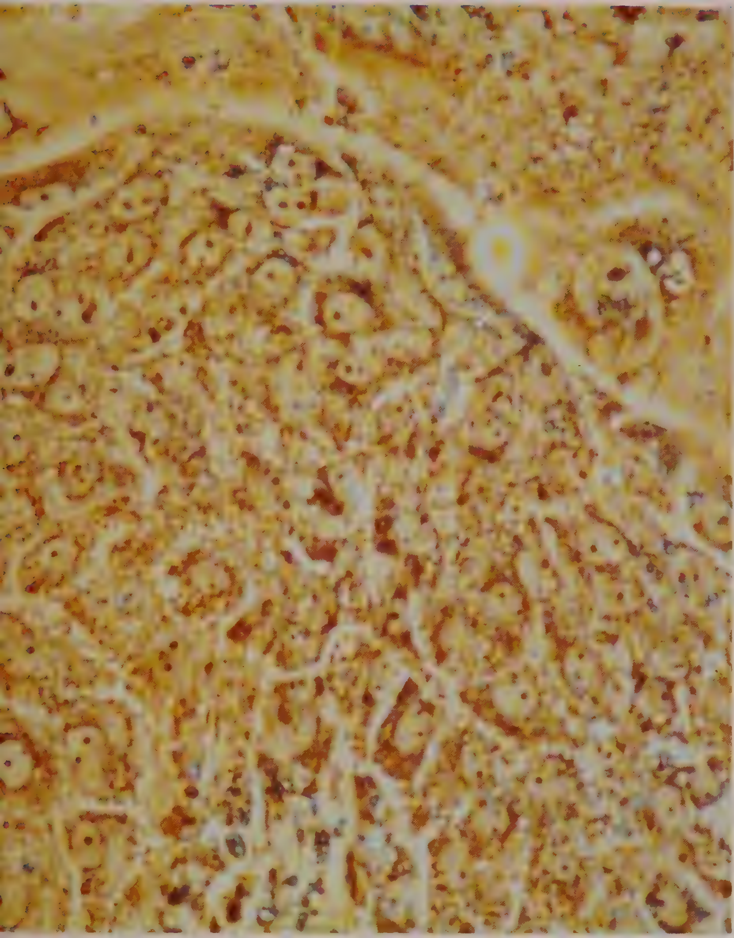
Comparison of an adult animal containing its different organs, tissues and cell types with the fertilised egg from which it develops shows just what a feat cell differentiation is. In the early embryos of higher animals some cells are totipotent – i.e. have the capability to differentiate into any type of cell. This capability is progressively lost during development as the cells commit themselves irrevocably to a "career" as a particular cell type – e.g. a liver cell or a brain cell. However, even in the adult some flexibility (pluripotentiality) remains, for example, stem cells in the bone marrow can differentiate into all the various cell types found in the blood. In plant cells differentiation is not irreversible: specialised cells can revert to meristematic form and develop into callus culture which can subsequently be induced to differentiate anew into different tissue types. Basic studies on the molecular biology of stem cells will provide clues about this fundamental difference between plant and animal cells.

To understand cell and tissue differentiation it is necessary to explore the mechanisms governing "decision–making" in stem cells. For example, these



cells have the ability both for self regeneration, to produce more stem cells, and for differentiation – what determines which pathway their progeny take and how is differentiation regulated to ensure that the right type of cell is produced?

Scientists at the AFRC Centre for Genome Research (CGR) at the University of Edinburgh are investigating the mode of action of Differentiation Inhibition Activity (DIA) which, as its name implies, prevents differentiation of embryonic stem cells. DIA is produced by differentiated cells



Unspecialised cells, such as this colony of pig stem cells, carry the genetic information for the whole organism. A better understanding of their biology could accelerate genetic improvement of livestock.

and acts as a brake to prevent the stem cell population from differentiating. It thus influences the interdependence of stem cells and their differentiated offspring. *In vitro* studies show that its effects are profound. Continuous application of DIA is needed to prevent cells from differentiating, but once it is removed, cells start to differentiate and subsequent re–introduction of DIA has no effect. It is important to understand what changes take place in embryonic stem cells at the commencement of differentiation so that they no longer respond to DIA. Part of the programme at the CGR is aimed at identifying the cell surface receptor for DIA and studying its regulation. DIA can be used in the laboratory to grow pure populations of embryonic stem cells, but it is uncertain whether or not it may have similar effects on some kinds of somatic stem cells – if it does, it could provide a way of isolating somatic stem cells for manipulation.

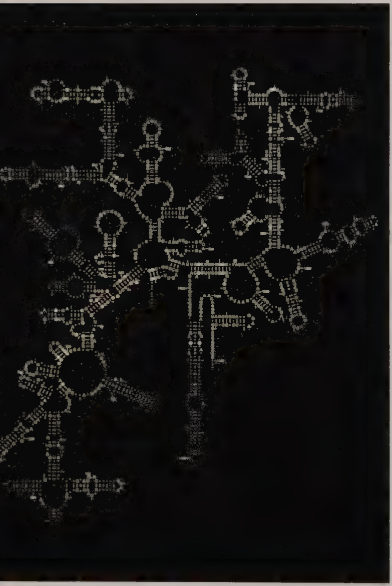
Procedures for the derivation of embryo–derived stem cells from mice, and techniques for the utilisation of such cells in the generation of transgenic mice, are well established. The ease with which the mouse cells can be manipulated genetically *in vitro* prior to their re–incorporation into a viable embryo has led to huge advances being made in the areas of mammalian molecular genetics: specifically by allowing the introduction of exogenous genes, or the modification of endogenous genes into the genomes of fertile animals. The availability of embryonic stem cells from species other than rodents would be of great relevance to studies in comparative development. Scientists at the AFRC Institute of Animal Physiology and Genetics Research (IAPGR) at Babraham, in collaboration with the University of Cambridge, have reported the derivation and culture of embryonic cell lines from pigs and sheep. They are attempting the re–introduction of the porcine cells into host blastocysts with the aim of deriving chimaeric animals which can transmit the embryonic cell line to their offspring. This would confirm the pluripotency of the cell lines, and demonstrate the feasibility of using the stem cell approach to transgenesis in species other than the mouse.

In vitro propagation and manipulation of embryonic stem cells holds enormous potential for applications in the agricultural, medical and veterinary sciences. Foreign genes, for example, those coding for disease resistance, could be introduced; and resident genes could be modified, and their regulation manipulated. Stem cell technology also provides a way of constructing animal cell models of human diseases for use in pharmaceutical testing.

BACTERIAL FAMILY TREES AND TELL–TALE SIGNATURES

Studies on the molecular relationships of bacteria are revolutionising the way bacteria are classified and identified. This new approach has wide–reaching implications for microbial ecology across the biological sciences, and specifically, for example, in the detection of emerging pathogens and recognition of new spoilage organisms.

Probably less than 1% of the world's bacteria have been identified, even for the well studied medium of human sewage it has been estimated that only about 10% of the organisms have been described. But this is just the tip of the iceberg of our ignorance because identification has been limited to those organisms that can be cultured, and there is now a growing recognition that a large proportion of bacteria are not culturable using available methods. Even when identification has been possible, it has been based largely on behavioural characteristics, and these have proved to be unreliable and unstable indicators of genetic make–up.



A molecular clock? The sequence of bases in this RNA molecule from a bacterial cell provides clues about its evolutionary history and reveals its kinship to other organisms.

Now, scientists at the AFRC Institute of Food Research (IFR) are at the forefront of a new molecular approach that classifies and identifies bacteria into stable genetic groupings. This provides a rapid and objective way of measuring the interrelatedness of bacteria and provides a framework against which new species can be examined. It can be used even on mixed populations of bacteria containing species that cannot be cultured.

This new approach is based on mapping the sequence of bases in the ribonucleic acid of the ribosomes, the sites of protein synthesis in the bacteria. These molecules known as rRNA can be regarded as chronometers that record the ancestral interrelatedness of bacteria because their nucleic acid sequences contain regions that change at different rates during evolution. Parts of the sequences are highly conserved, i.e. they change only very slowly – similarity only in these regions indicates that organisms are distantly related. Other parts change more rapidly, and some very rapidly – similarities in the latter, for example, indicate closely related organisms.

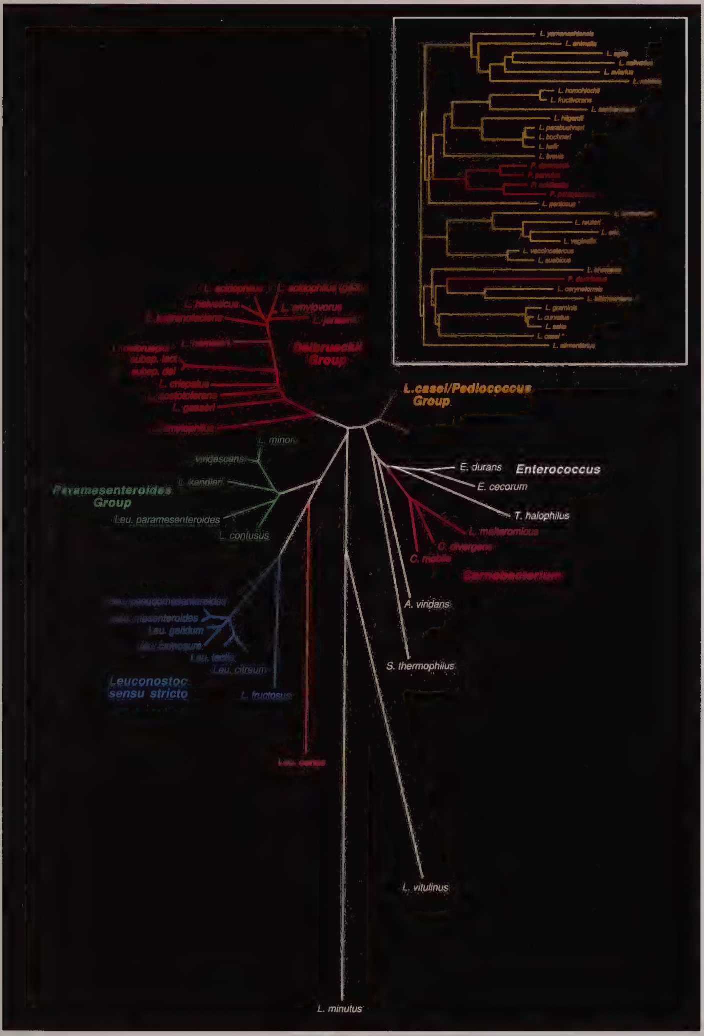
The IFR scientists have used this rRNA technology to study interrelationships of a wide range of microorganisms (e.g. the food pathogen *Clostridium botulinum*). Traditionally, classification of *C. botulinum* has hinged on the organism's ability to produce botulinum toxin, and seven toxin types (A – G) have been recognised. But some of these show considerable phenotypic variation. For example, type B contains proteolytic and non–proteolytic forms. When the rRNA of these two types was sequenced they were found to be different species!

The technology

The success of rRNA mapping has been greatly facilitated by the rapidity with which data can be accumulated. An rRNA sequence can be obtained within 36 hours from a microcolony of just 100 cells using a technique called the polymerase chain reaction (PCR) which allows analysis of the ancestry of non–culturable species. By extracting the total nucleic acid from a mixed population of organisms, and using PCR random cloning, fragments can be sequenced and used to construct "family trees".

Because fast changing sequences of rRNA give rise to "signatures" for each organism, they can be targeted to aid identification and detection. At IFR, diagnostic regions are being identified within the sequences of small sub–unit rRNA molecules from important spoilage and pathogenic species including *Listeria* spp. Industrial support is contributing to development of rRNA probes for *L. monocytogenes* and mastitic streptococci and staphylococci.

Another area in which rRNA technology will be particularly valuable is probiotics – "cocktails" of harmless bacteria used, for example in veterinary medicine, as prophylactic treatment against pathogens. Companies making probiotics



Evolutionary family tree of *Lactobacillus* and other lactic acid bacteria. The evolutionary distance between two species is the sum of the total branch lengths.

Inset: Molecular mapping can throw up some surprises and confound traditional approaches – the species shown in red are globular-shaped, yet they map amongst the rod-shaped organisms.

need to know precisely what they contain in order to eliminate any risk of transferring potential pathogens. They would also benefit from knowing the signatures of their organisms, for example, so that these could be eliminated in any subsequent investigations of possible sources of infection.

The IFR team is a world leader in identifying the molecular relationships of bacteria, and has extensive international collaborations. These include work with the Centres for Disease Control, Atlanta, USA; and with university groups in Spain and Belgium. Together with the Pasteur Institute, Paris, the Technical University of Munich and GBF, Braunschweig, Germany, support is being secured from the EC for a collaborative study to expand concepts of RNA technology and increase the database.

Clinical lactic acid bacteria

Lactic acid bacteria are widely distributed in nature. Some are spoilage organisms in foods and beverages, others are used in starter cultures in fermented foods which have an excellent record of food safety, and in probiotics. Over the past few years, there have been sporadic reports that organisms resembling lactic acid bacteria are implicated in some human infections. In collaboration with the Centres for Disease Control in Atlanta, USA, scientists at IFR, with support from MAFF, have used signature analysis of the rRNA to characterise hitherto unknown species of lactic acid bacteria. They have also confirmed that isolates from some of these human infections belong to genera and species previously considered to be non-pathogenic.

MAINTAINING EARLY PREGNANCY IN CATTLE

Very early in pregnancy the embryo signals its presence to its mother – communication which is mediated by interferons and is crucial to maintenance of the pregnancy. Understanding how this signalling works could lead to treatments to improve pregnancy rate in livestock by minimising early embryonic loss.

Pregnancy rates in domestic cattle are low. From every 100 dairy cows artificially inseminated or naturally mated, fewer than 55, and sometimes only 40, will go on to produce a live calf following any one ovulation.

In many cases pregnancy is achieved but the developing conceptus is lost very early on, typically within the second and third weeks after mating. This is about the time when the trophoblast signals its presence to the mother – so as to trigger the changes in her hormone levels that are needed to maintain the pregnancy. Failure of this signalling system seems the most likely cause of the low pregnancy rate observed. A better understanding of the mechanisms involved could help improve pregnancy rate in ruminants.

In 1987, the AFRC Research Group on Hormones and Farm Animal Reproduction, led by researchers at the University of Nottingham and IAPGR, Cambridge, purified and partially characterised the signalling protein from the trophoblast. Their results suggested that it was an interferon – i.e. a type of anti–viral protein produced by animal cells in response to viral infection. This has since been confirmed by cDNA sequencing. In fact, the trophoblast is now known to produce a family of interferons, all of which have anti–viral activity.

Recently, with continued AFRC support, scientists at the Institute of Zoology in London in collaboration with researchers at IAPGR, have developed cell culture systems for producing large quantities of trophoblast interferon. These use cells that have been genetically engineered to carry the trophoblast gene. As well as testing the ability of trophoblast interferons to maintain early pregnancy, this system is being used to explore how the activity of interferon genes is regulated. A sequence of DNA

Pregnancy rates in livestock could be improved by research which aims to minimise early embryonic loss.

(photograph: Milk Marketing Board.)

Hormonal maintenance of pregnancy

The maintenance of pregnancy depends upon continued secretion of the hormone progesterone from the corpus luteum, an organ formed in the ovary after ovulation. To be effective the trophoblast must produce a signal that switches off the chain of events which, in non-pregnant animals, leads to degeneration of the corpus luteum. It does this by secreting a protein which interacts with receptors on the surface of the endometrial cells which line the inside of the uterus. The interaction of the trophoblast signal with its receptors leads in turn to the disappearance of another endometrial receptor, one responding to the hormone oxytocin. It is the response of the oxytocin receptor to circulating oxytocin which stimulates secretion of prostaglandin $F_{2\alpha}$ from the uterus, and it is this prostaglandin that causes breakdown of the corpus luteum. So by targeting the oxytocin receptors, the trophoblast signal prevents degeneration of the corpus luteum and allows pregnancy to continue.

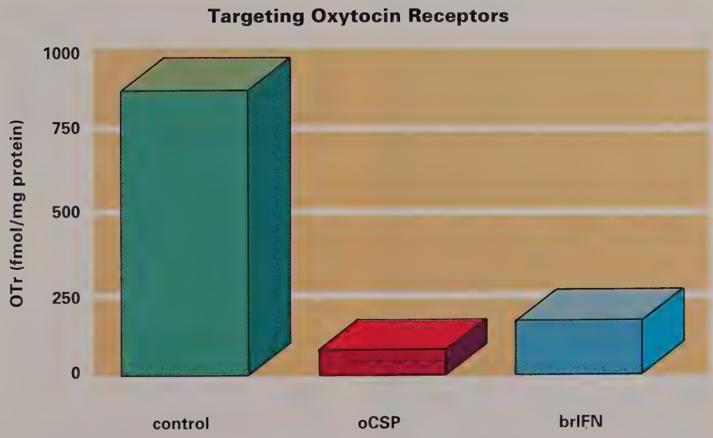
At the AFRC Institute of Animal Physiology and Genetics Research (IAPGR), the role of ovarian oxytocin in controlling the secretion of prostaglandin $F_{2\alpha}$ and cyclical changes in the endometrial concentrations of oxytocin receptors are being characterised. While at the SOAFD-funded Rowett Research Institute populations of sub-fertile *post partum* ewes and supra-fertile Chinese Meishan pigs are being studied to determine whether the timing and magnitude of biochemical signals during this critical period of pregnancy are associated with fertility.

Investigations at the Institute of Zoology are exploring the influence of trophoblast interferons on inhibition of oxytocin receptor concentrations and prostaglandin $F_{2\alpha}$ secretion and their interaction with steroids and other factors; and the influence of trophoblast interferons on endometrial protein secretion and the function(s) of these endometrial proteins during pregnancy.

that is upstream of a cattle gene which codes for a trophoblast interferon, and which may therefore be expected to promote expression of this gene, has been cloned and to it has been attached a reporter gene (one that codes for an easily detectable protein product). The whole construct has been inserted into cells growing in culture. The influence of different uterine factors is being studied by observing the extent to which they switch the promoter, and hence the reporter gene, on and off.

The success of this project emphasises the importance of bringing together individuals and organisations with complementary experience and expertise. The work could not have been done without combining molecular biology and whole animal physiology, and depended on the animal facilities of the University of Nottingham School of Agriculture. In this respect the productivity of a linked research group is greater than the sum of the parts.

Already, this work has led to a better understanding of the mechanisms that maintain the early stages of pregnancy in ruminants. It may in the future suggest new strategies for treating early embryo loss in livestock.



The effects of a developing conceptus in the uterus can be mimicked by giving interferons. Bovine recombinant interferon (brIFN) is almost as effective as interferons produced by trophoblast in culture (oCSP) in reducing oxytocin receptors.

CONTROLLING CROSS-MEMBRANE TRAFFIC

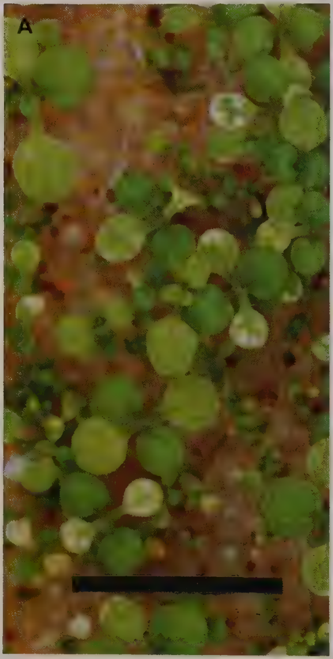
The molecules that govern movement of key compounds in and out of plant and animal cells are attractive targets for manipulating cell behaviour – not least because faulty transport across cell membranes is often associated with pathological conditions.

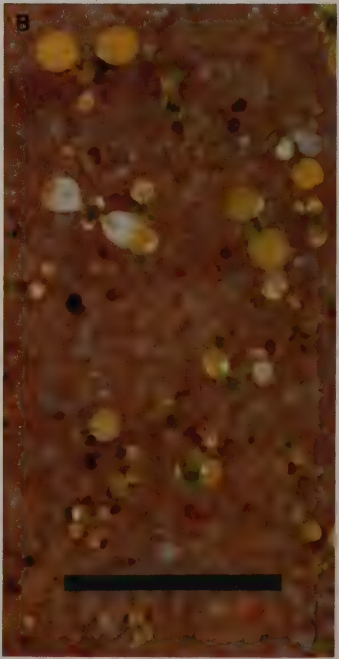
The membranes of red blood cells contain a pump which exports sodium from the cell and imports potassium. The selective blocking and unblocking of this pump has exciting implications for medicine. For example, treatment of cardiovascular disorders might be effected by modulating pumps to increase cellular levels of sodium and calcium ions, thus increasing muscle cell contractility.

Some sheep, which are otherwise normal, have a protein in these membranes which partially inhibits the pump. As a result, the cells are "leaky" and have higher sodium and lower potassium levels than normal. AFRC supported research at the University of Oxford, in collaboration with the AFRC Institute of Animal Physiology and Genetics Research, Cambridge, is investigating this so-called L-protein – the only known peptide inhibitor of the membrane pump.

Antibodies to the L-protein identified it as a polypeptide of molecular weight 25kD located deep within the membrane. Interestingly, although the L-protein acts on the inside face of the membrane, the binding of anti-L antibodies to the outside of the membrane releases L-protein inhibition on the inside, allowing potassium and sodium levels in the cell to return to normal.

The flow of molecules and ions, such as sodium and potassium, between a cell and its environment is controlled by proteins of the plasma membrane. These act as gates, pumps, receptors and enzymes. Here, we report three examples from current AFRC research: a sulphate transporter protein in plants, study of which is elucidating how plants regulate nutrient uptake; a receptor in insect nerve cells which responds to chemical signals from neighbouring cells, and which could be a target for novel pesticides; and a protein which inhibits transport of sodium and potassium in red blood cells, and which suggests new ways of treating cardiovascular and renal disorders.





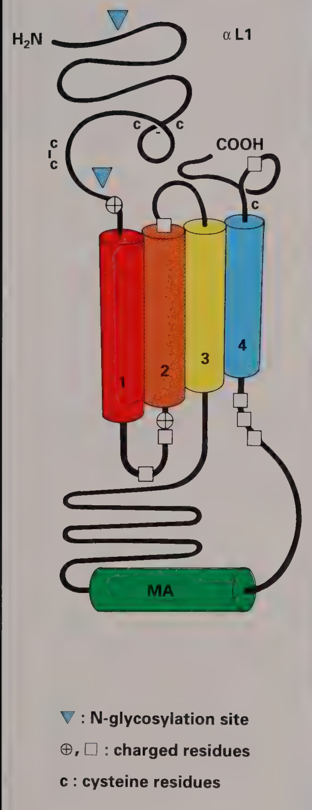
Arabidopsis **plants grown with nutrient lacking sulphate (A) or containing its toxic analogue, selenate (B). Some plants can survive selenate treatment, by failing to absorb or assimilate it. They have to be "rescued" by feeding them with the amino acid cysteine. (Bar: 5mm).**

When plants are starved of a nutrient, they respond by producing more of the transporter for that nutrient, thus enhancing their ability to scavenge from dilute solutions. This *induction by starvation* is being used by scientists at the AFRC Institute of Arable Crops Research at Long Ashton, as one strategy which may lead to the identification of the transporter for sulphate. Physiological evidence suggests that this transporter works by binding sulphate and hydrogen ions at the outer face of the membrane, re-orientating part of the polypeptide chain and releasing them

Nerve cells communicate with each other by chemical signals known as neurotransmitters. Defects in this signalling are implicated in the human disease *Myasthenia gravis*, for example, and in many degenerative diseases of the brain. The membrane receptors for certain neurotransmitters are targeted in treatments for depression, anxiety and similar conditions.

Neurotransmitter receptors are being studied at the AFRC Institute of Animal Physiology and Genetics Research at Cambridge. One class of receptors, which are proteins that span the nerve cell membrane, have a dual role: to bind a specific neurotransmitter (e.g. acetylcholine) and to alter their structure so as to open transiently a channel in the membrane through which ions may pass. Different receptors allow different ions to pass through.

The AFRC scientists, in collaboration with the MRC Molecular Neurobiology Unit, have built up a detailed picture of a neuronal acetylcholine receptor/channel molecule from locust – insects are the world's richest source of these particular receptors. The scientists have cloned the gene for a subunit (called αL1) of a fast–acting locust acetylcholine receptor and expressed it in cultured amphibian egg cells, where it produces a functional receptor. Regions that span the membrane, those that bind the neurotransmitter, and those that form the cross–membrane channel, have each been identified. This polypeptide also binds insecticidally active molecules called nitromethylenes – an improved understanding of its function is contributing to the design of a new generation of safer crop protection agents.



Schematic representation of the topology of the α L1 subunit of the locust neuronal nicotinic acetylcholine receptor. Four membrane spanning α-helices (1-4) in each subunit are shown as cylinders. MA represents a predicted amphipathic helix.

into the cell. Electrophoresis of proteins from pure plasma membrane preparations from cultured tomato roots reveals a few polypeptides whose abundance and rate of synthesis change with sulphate starvation. These proteins, now being obtained in larger amounts, are being used to produce antibodies which, in their turn, can be used to purify larger amounts of protein. Sequencing the protein will allow development of chemical probes which can be used to identify messenger RNAs and thereafter the genes of the transporter.

In an alternative strategy, mutants are selected with altered or defective sulphate transport systems. *Arabidopsis thaliana* has been used for this, mutagenised populations being screened against selenate, which is a toxic analogue of sulphate. Several lines with altered sulphate transport capacity have been obtained, and, in these, the genes for the sulphate transporter may be identifiable by restoring transporter activity in the mutants by complementation with genes from a wild–type genomic library.

The expression of nutrient transporters is normally tightly controlled by the rate of growth. Breaking this linkage by genetic manipulation might allow crop plants to gather, in excess of immediate requirements, leachable nutrients such as sulphate and nitrate, which could be stored in vacuoles for subsequent use. Such changes might improve the catchment of applied nutrients by crop plants.

CLOSING–IN ON THE CAUSATIVE AGENT OF BSE

Bovine Spongiform Encephalopathy (BSE) is one of a family of disorders that includes the centuries–old disease of sheep, scrapie. It seems that small changes in a protein normally found in the brain appear able to influence the incidence and course of disease following exposure to an as yet unidentified infectious agent. AFRC has boosted its research on the spongiform encephalopathies with a new £9M programme aimed at identifying the infectious agent and the mechanisms of pathogenesis.

There is conflicting evidence about the infectious agent of scrapie–like diseases. There are different strains of these agents and they can "mutate". Normally in pathogens, nucleic acids encode strain variation but ultraviolet and ionising radiation, which destroy nucleic acids, have little effect on the infectivity of scrapie. On the other hand, chemicals harmful to proteins can reduce infectivity. These data suggest the agent may be either simply protein or a highly–protected composite of protein and nucleic acid. The glycoprotein PrP, a normal component of brain tissue, is a candidate for the protein part of the agent.

Antibody–labelling of abnormal PrP in a brain affected by scrapie. Different patterns of labelling are associated with different strains of the disease.

The abnormal fibrils (Scrapie Associated Fibrils or SAF) found in chemically treated extracts of brains of sheep with scrapie co–purify with infectivity and are composed of PrP. Each microgram of SAF contains about 10^9 infectious particles, so there are about 10^5 molecules of PrP per infectious particle. In in–bred strains of mice experimentally exposed to scrapie there is a standard dose response relationship between the amount of infectivity (and SAF/PrP) an animal is exposed to and the survival time of that animal.

Scientists at the AFRC/MRC Neuropathogenesis Unit, part of the AFRC Institute for Animal Health, have identified genetic loci in sheep (*Sip*) and mice (*Sinc*) that influence survival time. Two forms of the *Sinc* gene have been found. They are associated with PrPs that differ by just two amino acids (out of a total of 232). Sheep with different forms of the *Sip* gene have also been shown to have slightly variant forms of PrP.

Scrapie and BSE – the same but different?

About twenty strains of scrapie have been discriminated by differences in their incubation time, and the patterns of brain degeneration they cause. Scientists at the AFRC Institute for Animal Health have recently shown that the incubation period for BSE is different from these characterised strains of scrapie. However, different strains of scrapie were first isolated ten to twenty years ago, and under natural selection in the field, they may have changed, perhaps now more closely resembling BSE. A new MAFF–supported programme at the AFRC/MRC Unit is investigating the similarity of contemporary scrapie with the "classical" strains. There is no evidence of significant strain variation in BSE, either in incubation period or the pattern of lesions in the brain.

Transgenic experiments being conducted in collaboration between scientists at the AFRC/MRC Unit and the AFRC Centre for Genome Research should indicate how changes in PrP structure influence disease susceptibility. For example, it will be possible to see whether mice carrying the gene for sheep PrP become more susceptible to scrapie; and how different types of PrP affect scrapie incubation times. By targeting the expression of transgenes to specific areas of the brain, it should also be possible to explore the significance of observed differences in patterns of degeneration with different strains of scrapie.

AFRC scientists have recently elucidated the nucleotide and amino acid sequences for the bovine PrP gene. This work, which has been conducted in collaboration with the MAFF Central Veterinary Laboratory, provides the first clue about molecular differences which could determine BSE susceptibility.

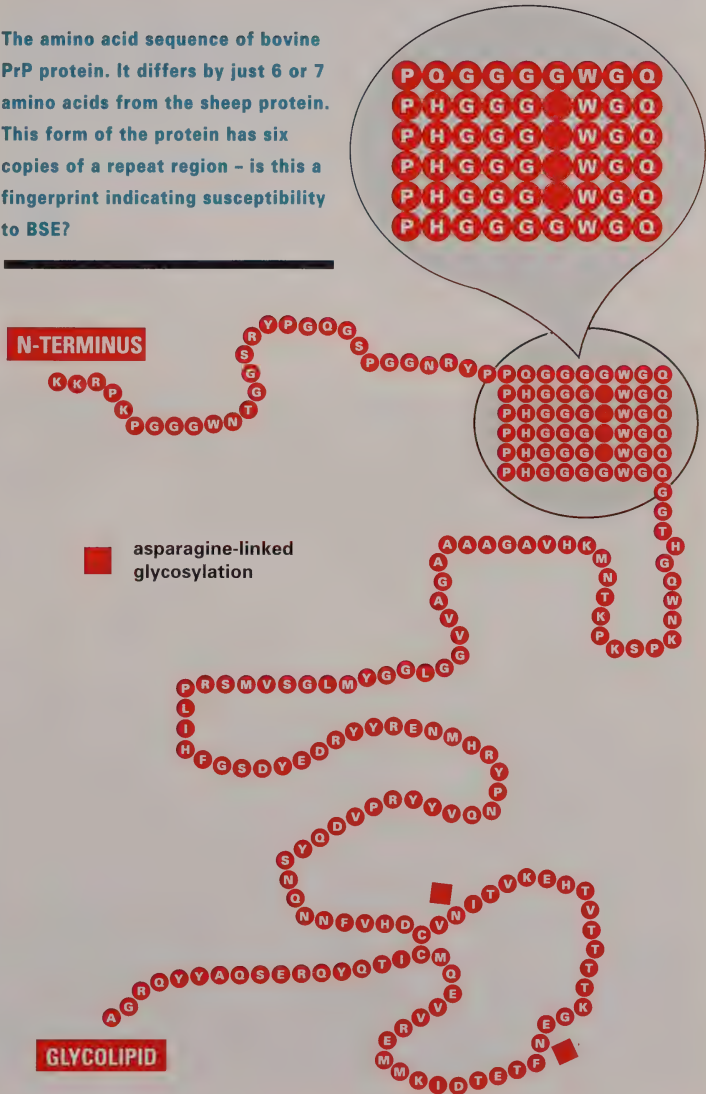
Two forms of the cattle PrP gene have been found – which code for proteins which have either five or six copies of a repeated sequence of eight amino acids. In twelve cattle examined, four carried one gene for the 6–copy protein and one for the 5–copy version – i.e. they had inherited a different PrP gene from each parent. None of these cattle had BSE. The other eight had received the gene for the 6–copy protein from both parents – and of these, two developed BSE. Interestingly, the structure of PrP appears to be very similar in all mammals, and presence of an additional amino acid repeat domain in humans is associated with Creutzfeldt–Jakob disease. But, despite much epidemiological investigation, there is no evidence that human transmissible spongiform encephalopathies originate from animals, including those infected with scrapie or BSE.

It would help if more was known about the role of PrP in normal brains. Its highly conserved structure suggests an important role; and comparison of its sequence with those of proteins whose function is known, suggests at least one role for PrP as a regulator of the synthesis of receptor molecules for neurotransmitters. Another approach is using stem cell technology to introduce alterations in the PrP gene and study their effects on function. Transgenic systems will provide useful experimental models in which to study the spongiform encephalopathies of animals and man.

£9M programme

In December 1990, AFRC launched a new four-year coordinated programme on the biology of the spongiform encephalopathies, totalling £9M. This involves awards to researchers in seven universities, as well as the AFRC Institute for Animal Health. The programme includes projects on *in vitro* models of the human diseases and crystallographic studies on the structure of PrP protein.

The amino acid sequence of bovine PrP protein. It differs by just 6 or 7 amino acids from the sheep protein. This form of the protein has six copies of a repeat region – is this a fingerprint indicating susceptibility to BSE?



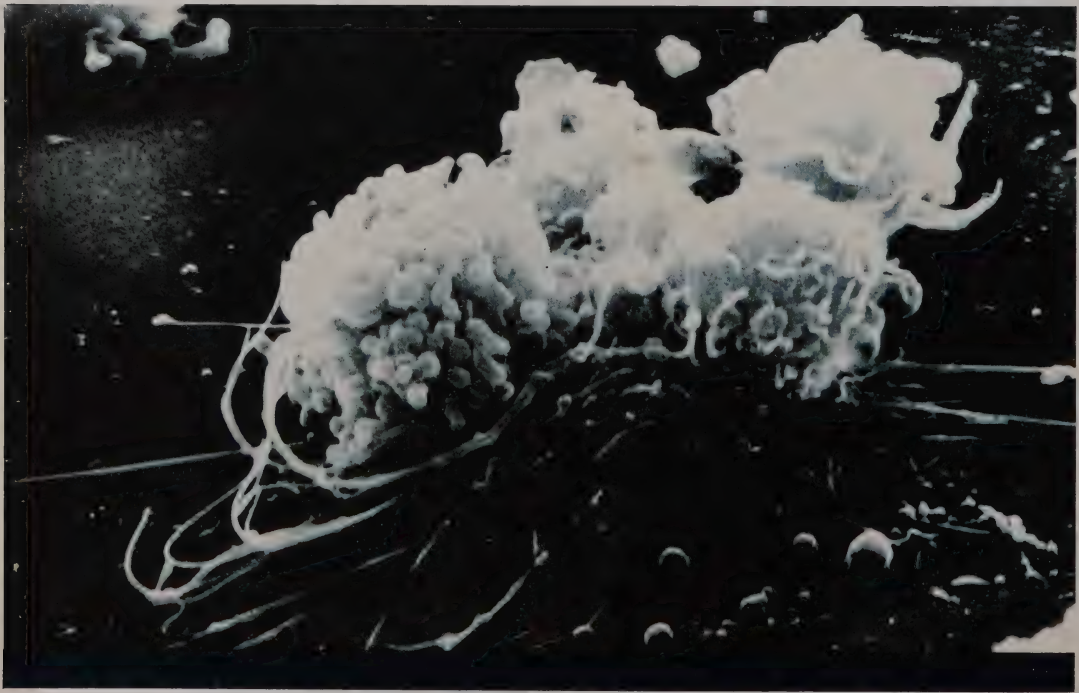
STUDYING THE IMMUNE RESPONSE - AS IT HAPPENS

Unlike many other systems the immune system contains roving populations of cells which circulate and recirculate via the blood stream and the system of lymphatic vessels which permeate the body tissues. As if this didn't introduce complexity enough into orchestration of the body's defence system, the scale of cellular traffic is enormous – literally hundreds of millions of cells passing through the lymphatic system each hour. So it is not surprising that* in vitro *systems which measure the function of immobile cell populations cannot, on their own, explain the physiology of the immune response.

AFRC–supported researchers in the University of Edinburgh, Department of Veterinary Pathology are among only 3 groups in Europe who use lymphatic cannulation to study the behaviour of the different cell types that make up the immune system. This *in vivo* work is coupled with powerful molecular technologies to analyse the function of the genes and proteins of the immune system within the context of *in vivo* functions of the immune system in health and disease. The work is pursued in close collaboration with the SOAFD-funded Moredun Research Institute whose work on the genomic arrangement of the Major Histocompatibility Complex (MHC) and established record in disease investigation in sheep is complementary to the University based research programme. Together these two groups constitute a major international strength in ovine immunology and immunopathology.

The lymph node is the heart of the lymphoid system, and the level of analysis possible in the sheep makes this species the ideal model for studying lymph node physiology and pathophysiology. By cannulating the lymphatic ducts before they enter or after they leave individual lymph nodes, the Edinburgh researchers can monitor populations of cells entering and leaving the node, and study the kinetics of cell traffic during an immune response. For example, the Edinburgh group have identified changes in the expression of immunologically important cell surface molecules that occur during an

Antigen presentation: a scanning electron micrograph of an antigen presenting cell with characteristically long dendritic processes presenting antigen to T cells which adhere to its surface.



immune response. They can also monitor levels of cytokines – the short range message molecules, including interferons and interleukins, by which immune cells communicate with each other. Such correlation of physiological changes with lymph cell function is already providing valuable insights into several pathological conditions in sheep, including that caused by the Maedi–Visna virus, the ruminant lentivirus with close similarities to the AIDS virus in man, which attacks some cells of the immune system.

Three types of cell (antigen presenting cells, T cells and B cells) form the core of the immune system. The antigen presenting, or accessory, cells bind and internalise antigenic ("foreign") molecules before processing them and presenting them to helper T cells which express receptors for individual antigens and orchestrate the response including the production of antigen-specific antibodies from the B cells.

Work at Edinburgh has shown that afferent lymph (i.e. that flowing to the node) contains relatively few cells, mainly T cells, 1 – 10% antigen presenting cells, and less than 10% B cells. Lymph leaving the node typically contains 10–fold more cells, comprising about 30% B cells and 70% T cells.

One area of interest is how antigen presenting cells present antigen to T cells. Several presentational molecules are implicated, including MHC Class I and II proteins which bind antigenic peptides, and a family of molecules known as CD1 which are also involved in activating T cells. By studying antigen presenting cells of the afferent lymph, the expression of these molecules in response to an antigenic stimulus has been compared in antigen–naive sheep (i.e. those not previously exposed to antigen) and primed sheep which have seen the antigen before. The results have shed new light on how the immune response is regulated. In the primary response in antigen–naive sheep, there were very transient increases in CD1 expression in some antigen presenting cells, but no alterations in cell kinetics or MHC Class II expression. On the other hand, in the primed sheep there were profound changes in cell output, characterised by a three–fold fall in cell numbers on days 1–3, followed by a five–fold rise on day 5. MHC Class II expression by antigen presenting cells increased five to six–fold by day 5. There was also a substantial increase in the proportion of T cells expressing MHC Class II. In functional terms, antigen presenting cells from the primed sheep had an increased capacity to stimulate T cell proliferation and were up to six times more active in presenting antigen than were their naive counterparts.

Another aspect under investigation is how antigen presenting cells capture antigen in the first place. It has been assumed that this is achieved by antigen presenting cells engulfing antigen by phagocytosis or pinocytosis. But although this might account for uptake of the relatively high antigen concentrations typically used in *in vitro* assays, it has always been questionable whether it could fully explain the *in vivo* scenario where local antigen concentrations may be very low, especially in primary immune responses. The AFRC–funded group at Edinburgh used monoclonal antibody probes to see whether antigen presenting cells carried antibody themselves, and thus might be able to bind antigen. They found that the majority of antigen presenting cells in afferent lymph do indeed carry immunoglobulins. It is most likely that these are "natural" poly–reactive IgM antibodies, with a role in concentrating and processing antigen, an essential and first step in the successful initiation of a primary immune response.

Similar strategies are being used to explore the role of other cell surface molecules on antigen presenting cells, including those concerned with signal transduction and adhesion. Other work by the group has shown that the uptake of antigen by antigen presenting cells *in vivo* is greatly enhanced if it is complexed with IgG antibodies. In secondary responses, therefore, antigen uptake is facilitated by antigen/antibody complex formation. These results have a direct bearing on the development of novel vaccination strategies.

Links with the Moredun Research Institute (MRI)

Research at the MRI on the bacterium *Chlamydia psittaci*, the cause of enzootic abortion of ewes (EAE), has shown that a native as well as a genetically recombined chlamydia antigen will, when used to vaccinate susceptible sheep, confer significant protection against EAE. Responses to *C. psittaci* are being assessed by lymphatic cannulation. Joint research between IAPGR, Cambridge and MRI has also defined, by molecular cloning, many of the genes encoding MHC Class II antigens of the sheep. Similarly, MRI–based research has been responsible for the characterisation and cloning of a number of cytokine genes. The establishment of an AFRC–funded linked group with Edinburgh University's Department of Veterinary Pathology gives added strength to their programme of molecular research on EAE.

ADVANCES IN GENE IDENTIFICATION AND MAPPING

AFRC scientists are world leaders in the race to identify and map genes of agricultural importance. Some of the major developments are outlined below.

Genes that control flowering

In December 1990, scientists at the John Innes Institute (IPSR) reported the isolation and identification of a single gene which is required for flowering. This is the first time a flowering gene has been isolated from a plant and this breakthrough now permits the mechanism of flowering to be studied at the molecular level. The gene, known as *flo*, acts very early in flowering and appears to be a master gene which can trigger many others required for the correct development of flowers. The gene was originally isolated from *Antirrhinum*, but is believed to control flower development in many, perhaps all, flowering plants. By modifying the *flo* gene and re–introducing it into plants, it may be possible to change the pattern of flowering in a controlled manner.

Work is continuing at the John Innes Institute (IPSR) to characterise the *flo* gene product and study its role in flower development. An award under the Japanese Government's Human Frontier Science Program is supporting collaborative research on the genetics of flower development between the John Innes group working on *Antirrhinum* and researchers in Pasadena, USA working on *Arabidopsis*.

A gene called *flo* appears to be a master gene controlling flowering in plants. When the *flo* gene of this *Antirrhinum* is inactivated the plant fails to flower, producing leafy shoots instead.

At the AFRC Institute of Grassland and Environmental Research, a non–flowering mutant of red clover (*Trifolium pratense*) has been genetically characterised. This mutant appears able to "perceive" increasing daylength, the normal trigger for flowering, but is unable to respond. It also has an upright, densely tillering growth habit, and lack of the pigment anthocyanin in its seed coat. Using backcrossing techniques allied to link electrophoretic markers, all of these effects have been ascribed to a single gene with two allelic forms: F (flowering) and f (non–flowering). This gene appears to exercise early developmental control over the flowering process, with environmental modulation applied via changes in endogenous hormone activity.

Mapping the genome of Arabidopsis thaliana

Thale cress (*A. thaliana*) has a particularly small and simple genome; for example, it contains about one sixtieth of the DNA content of wheat. This makes it an ideal model plant in which to study gene function and regulation, and the role of genes in plant development. The *A. thaliana* genome is being mapped in a co-ordinated programme involving researchers in universities, polytechnics and institutes throughout Britain, in a total of 34 projects. This is part of AFRC's £14M initiative on Plant Molecular Biology, instigated in 1989, and involves collaborations with other European and American researchers.

Techniques of "chromosome walking" based on identification of markers in overlapping fragments of DNA, and transposon tagging (see page 35) are among those being used to cover the entire genome and facilitate gene cloning in *Arabidopsis*.

An *Arabidopsis* stock centre is being established at the University of Nottingham. This will provide a point of collection, maintenance, cataloguing and distribution of mutant strains and ecotype collections of *Arabidopsis*. It is being funded by AFRC, the EC BRIDGE programme and the university.

The characterisation of the *flo* and F/f genes will provide further insights into the control of flowering in plants and could suggest strategies by which plant breeders could manipulate the quantity, timing and positioning of flowers.

This Arabidopsis seedling carries an antibiotic resistance gene which has been inactivated by the presence within it of a "jumping gene". Seedlings grown in the presence of the antibiotic turn white; however, when the "jumping gene" moves out of the genome, sectors of green tissue are produced in which gene activity is restored.

Mapping the pig genome

Compared with information about location and linkage of human genes, and those of the mouse, relatively little has been known about how the pig genome is organised. This is changing: scientists at the AFRC Institute of Animal Physiology and Genetics Research at Edinburgh, are coordinating a pan–European programme (PiGMaP) to map the pig genome. Sixteen laboratories are involved in eight countries. Among the benefits will be the identification of the combinations of genes that interact to influence economically important traits such as leanness and growth rate; and provision of genetic markers, making it easier for breeders to select for desirable characteristics. Also an expected similarity between pig and human maps suggests the possibility of developing porcine models of human diseases.

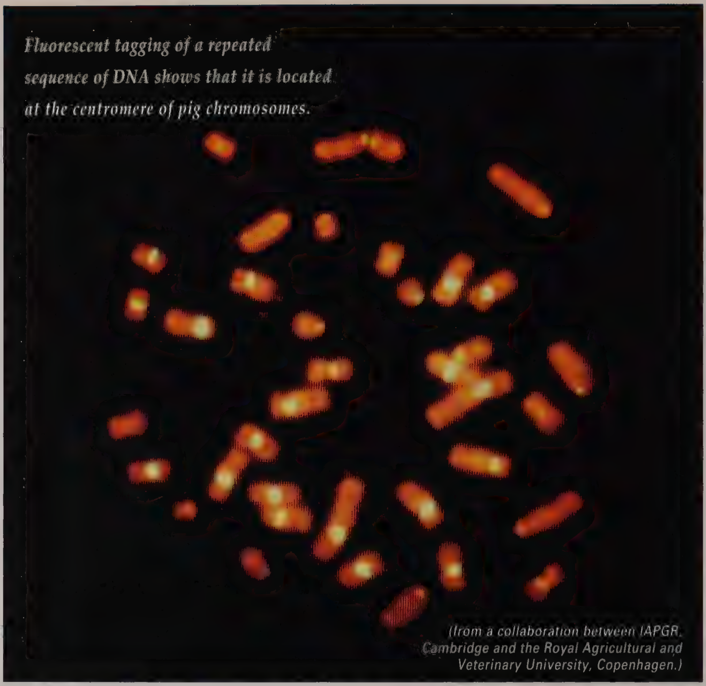
Two types of map are being constructed. The physical map shows where genes are located on the chromosomes. At IAPGR Cambridge, a fluorescence activated cell sorter is being used to separate and sort the chromosomes of the pig – possible because they exhibit a wide range of sizes and morphologies. This allows DNA sequences to be assigned to individual chromosomes. Fluorescent tags attached to DNA probes and allowed to hybridise *in situ* provide additional information about gene location.

The genetic map shows the extent to which different genes are linked, i.e. tend to be inherited together. Genetic maps are measured in Morgans; each Morgan representing the length of chromosome in which one recombinational event (or "cross–over") between a pair of chromosomes is expected to occur and thus generate a non–parental chromosome. The pig genome is expected to be about 30 Morgans, similar to the human; and the initial aim is to identify about 150 markers located at approximately 0.2 Morgan intervals.

Many commercially important traits, such as litter size and growth rate, result from the combined effects of several or many genes, known as quantitative trait loci (QTL). These can be studied using markers on the genetic map – variation of a QTL causes physical variation between

Chinese Meishan sow – genetic distance from European breeds is valuable in identifying genes that act in concert to influence commercially important traits.

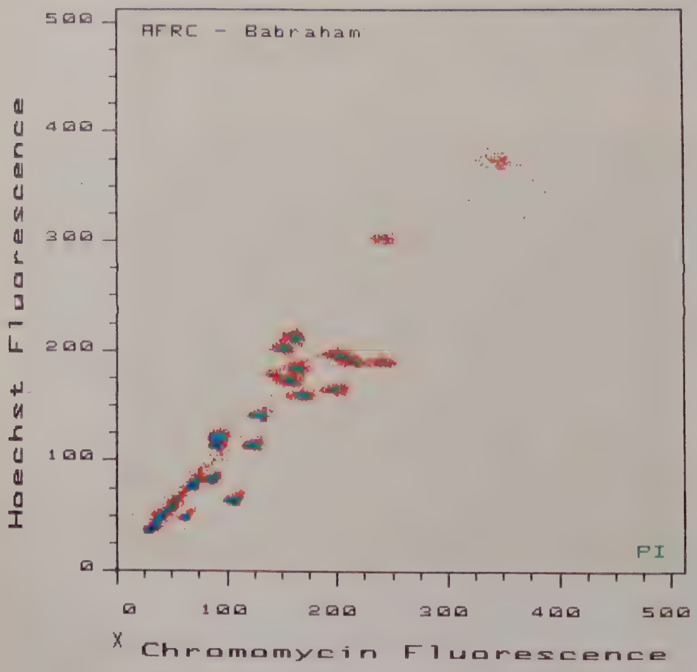
animals which can be associated with a linked marker by statistical techniques. With a complete genetic map, any QTL with an appreciable effect on a measured trait can be mapped in relation to the markers.



Fluorescent tagging of a repeated sequence of DNA shows that it is located at the centromere of pig chromosomes.

(from a collaboration between IAPGR, Cambridge and the Royal Agricultural and Veterinary University, Copenhagen.)

Divergent breeds provide the best way of detecting linkage between genetic markers. The Chinese Meishan pig is genetically very different from European breeds, and is being used in studies at IAPGR Edinburgh. Because this breed also differs phenotypically from its European counterparts, crosses will provide valuable information about QTLs controlling these differences. One Meishan/Large White reference population is being produced at Edinburgh for the PiGMaP programme, and similar populations are being produced in France and the Netherlands. There are also reference populations in Sweden and Germany which are based on crosses between wild boar and commercial European stocks. Collaborating laboratories work on the same reference material and exchange DNA and gene probes so that all of the information can be built into a single genetic map which can then be correlated with the physical mapping work to provide a comprehensive picture of how the pig genome is organised.



Separation of pig chromosomes on a dual laser fluorescence activated cell sorter. Each cluster represents one of 18 pairs of autosomes or the X or Y chromosomes.

"... Developments in molecular and cell biology, and in the engineering and information sciences, offer real possibilities for greater efficiency in agriculture, food manufacture and other industries .."

FRONTIERS IN

Technologies for Industry

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NEW ROLE FOR ENZYMES IN LOW–WATER SYSTEMS

Enzymes are more robust than has previously been imagined and will become more important in the industrial manufacture of fine chemicals, pharmaceuticals and food ingredients, than hitherto envisaged. Research is focusing on fundamental and applied aspects of biocatalysis in unconventional environments to bring about novel use of traditional enzymes.

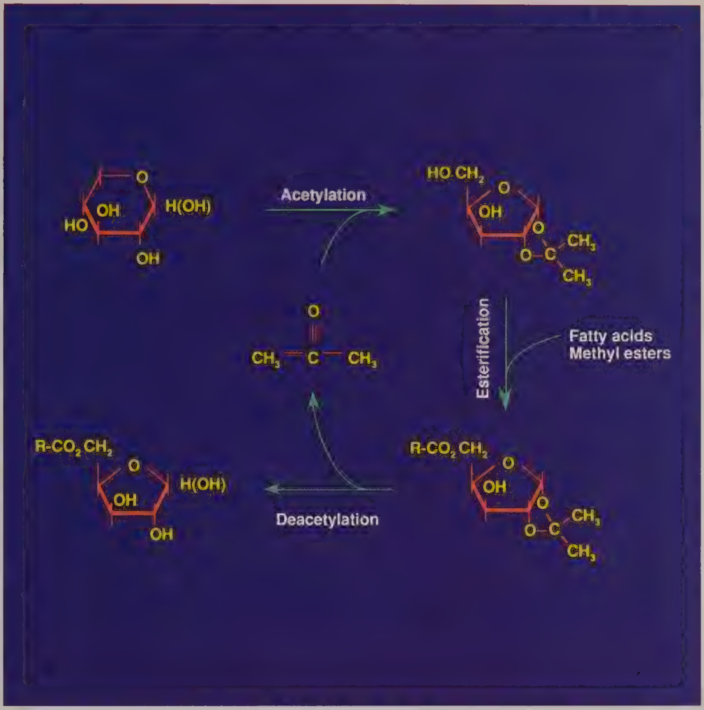
Enzymes have been used in food processing for centuries without any knowledge of the underlying principles involved. Only since the advent of modern biochemistry, have dedicated enzyme systems been developed for use in food manufacture. But whilst their potential as gentler alternatives to chemical processing has been recognised, it was assumed that enzymes would be unable to cope with the demands of long commercial operational periods and nearly water–free environments. Indeed the perception of enzymes as very delicate catalysts has hindered many of their potential applications in industry.

Only recently has it become clear that enzymes can function in conditions previously thought to be beyond their endurance. Even more exciting is the recognition that they can acquire new catalytic properties when removed from their conventional biological environment, and that their specificities can be significantly altered by changing their reaction media. There are several added advantages of using enzymes in solvents other than water. These include: greater enhanced operational stability of biocatalysts; no restrictions on reactant solubility; and ease of product recovery.

At the AFRC Institute of Food Research (IFR) scientists are engaged in fundamental and applied studies of biocatalysis in unconventional environments. Of particular interest is the adoption of a "reverse mode" by many enzymes when they are placed in low–water systems. This opens up opportunities for increased application of hydrolytic enzymes for synthetic purposes, thus adding to their traditional use which has been largely in degradative processes. Using hydrolytic enzymes in this way could obviate the need for the costly co–factors and activated substrates which are often required for their synthetic counterparts.

The IFR team is focusing mainly on exploiting lipases, peptidases and glycosidases in near anhydrous environments. Lipases, for example, are employed for synthesis of sugar–based emulsifiers, compounds which are currently produced chemically and used in a great variety of food formulations.

Many enzymes work in "reverse mode" when they are placed in low–water systems. Those traditionally used in hydrolysis to break down biological compounds can be used for synthetic purposes.



Synthesis of monosaccharide sugar fatty acid esters.

The solvent–free lipase–catalysed reaction has been carried out at eqimolar ratio of fatty acid to sugar acetal, to obtain mono– or di–esters respectively. High yields, typically 50–90% have been achieved. Moreover, the emulsifying properties of the enzymically produced products appear to be superior to those of their chemically prepared counterparts.

The feasibility of using proteinases in peptide synthesis is also being explored using low-water systems. As a result, a novel enzymic strategy based on "straight through" coupling of inexpensive amino acid esters by proteases in low–water environments has been developed. It seems possible to manipulate the specificity of the enzymes to ensure that the correct sequences are produced in 95% yields. The resulting dipeptides can then be taken directly to the next coupling step. Using this approach, precursors of two biologically active pentapeptides have been prepared in a three step synthesis on a gram scale.

Glycosidases are another large class of inexpensive and readily available enzymes whose synthetic potential has yet to be realised. In addition to reversible hydrolysis, they catalyse glycon transfer to non–specific acceptors and thus are very versatile catalysts. Alkyl β–glycosides, which behave in a manner very similar to that of sugar–fatty acid esters, but are stable in alkaline conditions, and thus usable in situations where fatty acid esters are inappropriate, have been produced by action of glycosidase in an aqueous–organic two phase system developed at IFR. The immobilised enzyme is suspended in a concentrated sugar solution (the aqueous phase) while long chain alcohol (acceptors of glycon) forms the organic phase. Using this system, the end products were synthesised in almost pure form. The enzyme was stable, despite operation at 60°C.

Continuing fundamental studies on biocatalysis in unconventional media will provide a better understanding of structure/function relationships in anhydrous conditions, and should help to answer questions about the different water requirements of different enzymes, and the relationship between an enzyme's activity and stability in low–water media. They should also suggest strategies for improving performance, leading to bioreactor and process design for specific purposes. Such methods of biocatalysis could offer attractive economic alternatives to conventional chemical processing in a wide range of industrial applications.

IMAGE ANALYSIS, NEURAL NETWORKS AND TRANSPUTERS

Intelligent machines are being developed for automated process control, inspection and grading – and even for husbandry management and improved animal welfare.

Image analysis mimics the processes of the human eye and brain, using a camera and a computer and memory system. Thus, it has many applications in replacing human inspection, for example, in difficult or hazardous situations; and it offers a tireless alternative for continuous observation in monotonous and repetitive tasks.

The image formed by the camera is fragmented into, say, a quarter of a million picture points or pixels. The brightness of each pixel is digitized for transmission to, and analysis by, the computer.

The scientific challenges in developing image analysis for agricultural and food production systems concern *recognition* and *interpretation*. Unlike manufactured objects, natural products are often irregular and vary in size and shape; and in living systems, they move! This almost infinite variety of potential images exacerbates the problem of interpretation, which in agricultural systems, anyway, is often subjective. A blemish on a fruit, and its implications for classification, are easily recognised by a human grader. But it is difficult to "explain" this process mathematically to a computer.

Image analysis goes underwater

Remote sensing of farmed Atlantic salmon in deep-water cages off the coast of Scotland presents even more demanding challenges for image recognition and interpretation. AFRC is funding a collaborative project between the AFRC Silsoe Research Institute, the University of Stirling's Institute of Aquaculture and several industrial companies – including a fish producer, feed manufacturer and marine engineering company – to develop a system to monitor the performance of fish production systems.

The aims include the provision of objective data about the numbers of fish, their average size and weight, and the size distribution within the group, so that feed requirements and market readiness can be accurately predicted. The computational challenges are the development of algorithms enabling the analyser to interpret highly complex images. In addition to the usual problems of recognising animals, the computer must cope with "contaminating" images of weeds and bubbles in the water, overlapping images as fish are observed in a group rather than singly, and the movement of the fish in three dimensions.

Strategies are being designed to meet these challenges using high-speed intelligent systems of image analysis.

At the AFRC Silsoe Research Institute, intelligent systems of image analysis are being developed. Computers are being "trained" to analyse situations which they have not previously encountered. Crucial to this approach are neural networks – biologically inspired computing techniques roughly analogous to the interconnecting nerve cells (neurones) of animal brains.

A neurone receives information via several input channels, integrates it and transmits output information along a single channel. Whether or not output is generated depends on the total stimulation input, each component of which may have a different importance or "weight". Silsoe researchers are among those elucidating the mathematics of computer systems that resemble these neuronal pathways. When computers are fed a series of different input patterns and associated output values, they may be programmed to "learn the rules" relating the two. This process of learning equips the computer to apply the rules to new patterns of input.

The Silsoe group have recently won support under the EC's CAMAR programme to explore intelligent blemish detection in agricultural produce. They will be collaborating with scientists in Spain, France, Denmark and Belgium.

Researchers at Silsoe are participating in a DTI LINK programme with Loctronic International on the use of transputers and parallel processing to accelerate automated inspection and grading systems. They have also participated in a successful Linked Research programme with the University of Wales, Cardiff.

Candid camera for better animal husbandry and welfare

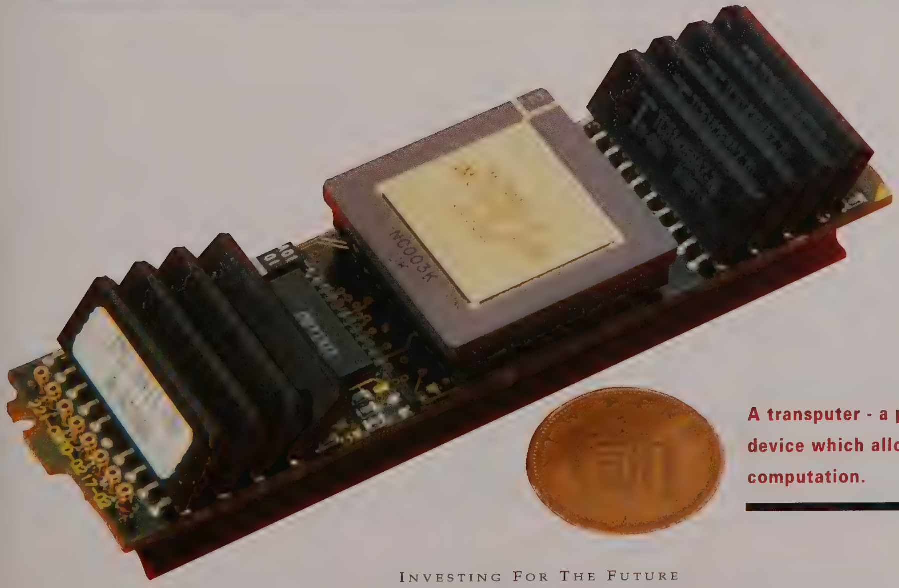
Image analysis is a totally non-contact method of sensing and inspection, highly suitable for monitoring livestock behaviour and performance.

At the AFRC Silsoe Research Institute, image analysis is being developed for remote weighing of individual pigs in penned groups. A camera installed directly above the drinker takes a plan view of each pig from which its area can be measured and its weight predicted to within 5%. The pig identifies itself to the analyser by an electronic tag. The animal is unaware that it is being "weighed" and remains unstressed – in marked contrast to manual weighing which is both stressful and time consuming.

The Silsoe system involves – i) separation of the image of the pig from the background by identification and joining of boundary points; and ii) identifying the head and rump ends of the pig. Structured lighting is being used to improve the quality of three-dimensional information that can be retrieved from the image, so that greater accuracy is achieved. This technology is being developed in collaboration with researchers at the University of Leuven, Belgium.

The camera above the drinker could also identify and report individuals that are visiting infrequently, perhaps a sign of illness. Another application is in farrowing. It is impossible to predict exactly when a sow will give birth. An image analyser trained to recognise the onset of farrowing could alert stockmen, and report any problems, such as an abnormal delay in the appearance of piglets.

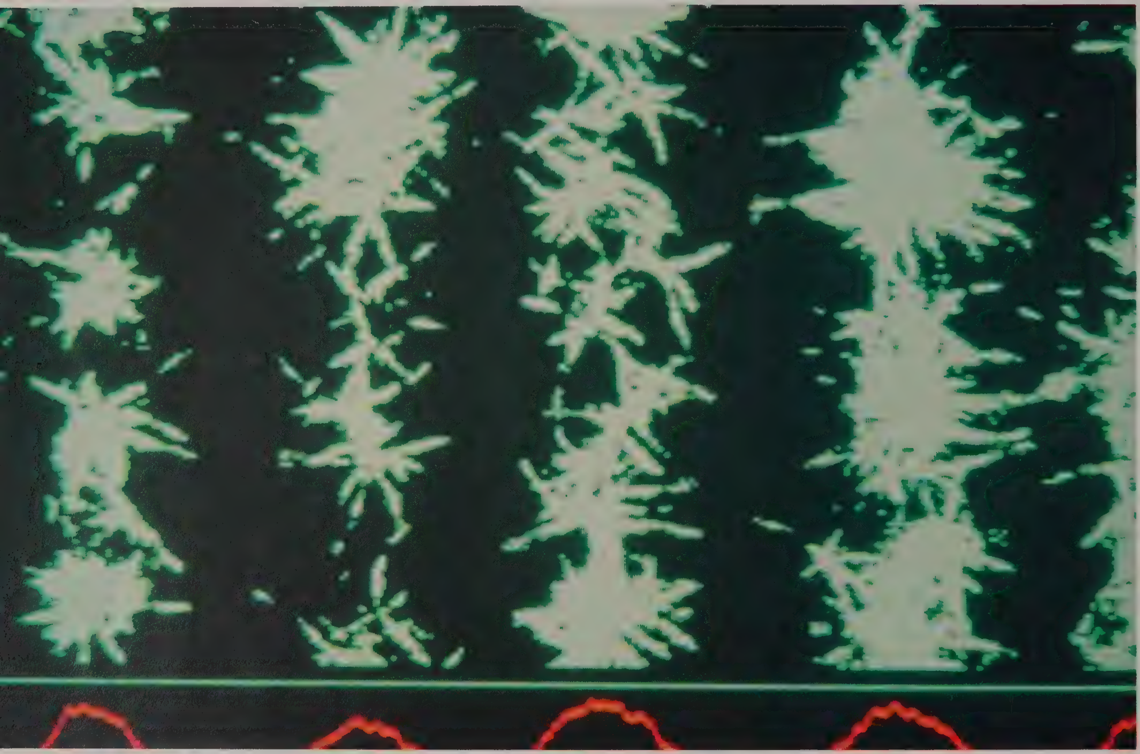
Model of a pig illuminated with striped light. 3-D information can be extracted from the distortion of the lines as they cross the pig surface.



A transputer - a parallel processing device which allows very rapid computation.

TARGETING FIELD OPERATIONS TO LOCAL REQUIREMENTS

Patch spraying methods are being developed to help eliminate wasteful "insurance spraying" of herbicides.



Binarised image of row crop.

Traditionally, agricultural operations are conducted uniformly on a field–wide basis. But most fields are not uniform: there are in–field variations in soil type, slope, aspect, soil moisture and fertility. Many important grass weeds in cereals, for example, are known to grow in patches which are fairly stable from year to year. Targeting the application of herbicide to weed density is one example of the concept of "spatially selective field operations" being developed at the AFRC Silsoe Research Institute.

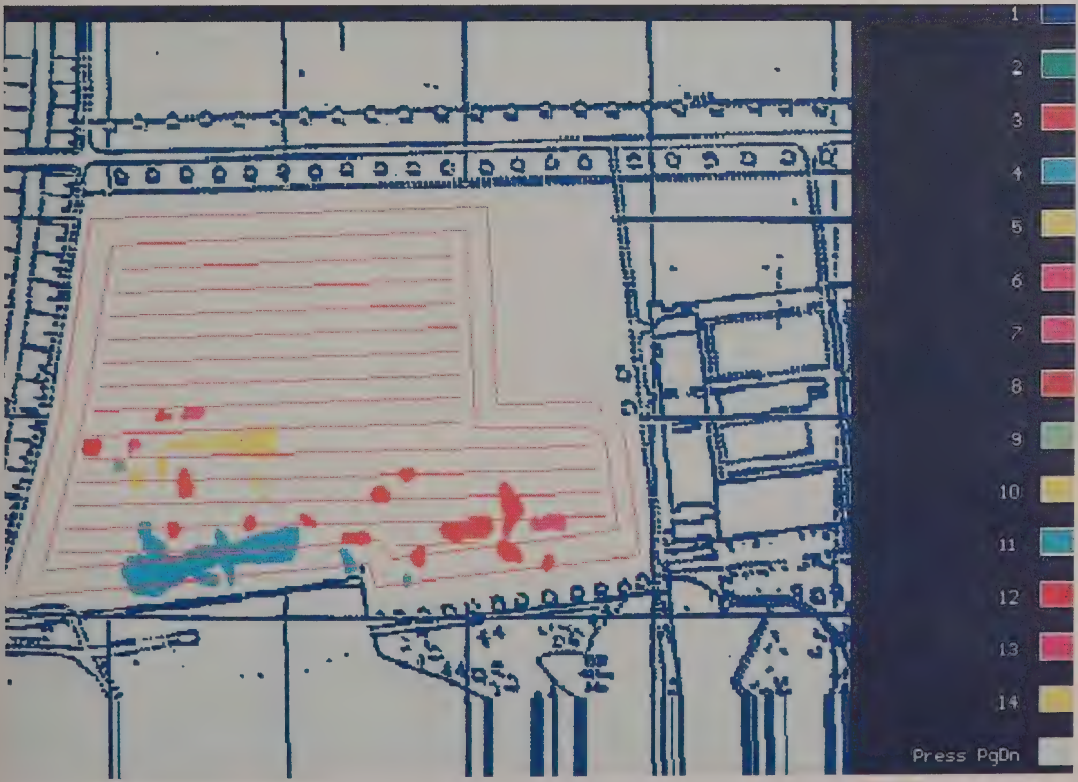
There are four key elements: sensing methods for detecting the weeds; a system for mapping their distribution; a location system by which the sprayer knows its position in the field and can relate this to the weed map; and a controller that uses the data on weed species and density at the location of the sprayer to direct herbicide dosage.

An approach being examined is the treatment of the whole field with a low dose background spray of herbicide. Where weed patches are detected, the dose is boosted to a level dependent on the density and species of the weed. A number of methods are being used throughout the growing season for collecting data from which the weed maps can be generated. These include detailed field walking and the analysis of field images from airborne platforms such as full–scale and radio–controlled model aircraft.

The work has also examined the possibility of using vehicle mounted image analysis systems for weed detection. High resolution sensing is required because some prevalent and competitive weeds such as cleavers, wild oats and mayweed can reduce cereal yields by about 2% at densities as low as one or two plants per square metre. Algorithms have been devised to discriminate between weeds and crop based on identifying weeds growing between the crop rows. This approach is limited to the early period of growth when weeds can be reliably discriminated from crop by image analysis. A further limitation relates to the number of cameras and the extent of the analysis required to cover the full width of a typical sprayer operating at speeds above 8 km/h.

A prototype controlled rate sprayer will be ready for evaluation by Autumn 1991. In this system a PC mounted on the sprayer vehicle combines information about the vehicle's location with that from a map of weed distribution. The PC outputs to a controller which determines the rate of herbicide application and switches on and off groups of nozzles along the sprayer boom. Field experiments with a 12 m wide sprayer operating in tramlined cereal crops and examining the biological response of fields treated in patches are being planned in collaboration with the AFRC Institute of Arable Crops Research at Rothamsted. The Silsoe scientists are also in contact with research groups in other European countries and the USA on spatially selective applications, particularly of fertiliser.

A field map superimposed with weed patches and tramlines used in vehicle location.



BUSINESS DECISION SUPPORT SYSTEMS IN AGRICULTURE

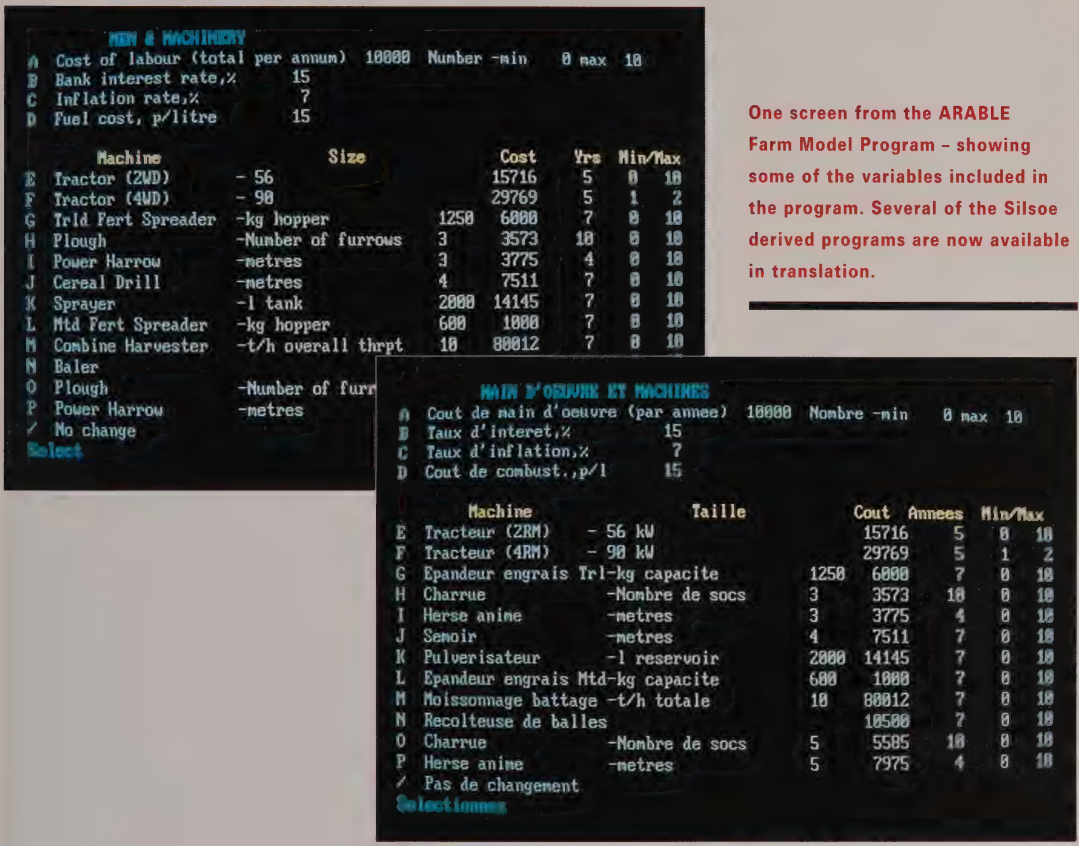
Good business management depends upon good information – in farming as in any other business. Research is improving the predictive capability of mathematical models of farm processes which, in the form of interactive computer programs, can aid farmers' decision making. The programs allow rapid evaluation of, for example, the profit and cost implications of a wide range of operational variables.

Many farm computers are currently used solely to record yields or field operations. New and improved interactive programs are now allowing on-farm evaluation of, for example, predicted yields from known inputs and weather data, predicted market dates, and a breakdown of operational costs for a range of farm processes.

Most of the mathematical models in use by agricultural researchers are based on the results of carefully controlled experiments. A major challenge to Decision Analysis research is to make these models more robust for real world applications.

All models are necessarily simplifications based on the best information available. At the AFRC Silsoe Research Institute, work is in progress to enable models to adjust themselves to actual data, so correcting the tendency for predictions to drift away from reality. Most agricultural processes contain inherent uncertainty due to external factors, particularly the weather. Uncertainty analysis techniques are being investigated that will enable the risks involved in particular situations to be incorporated. Further work aims to combine mathematical models with current data to reduce uncertainty about the future. Effort is also being made to optimise decisions from microcomputer–based models through techniques such as linear programming and non–linear optimisation and to achieve a better understanding of how models can contribute to strategic and tactical decision making.

Examples of models that support strategic decision making are those for labour and machinery planning. The most profitable combination of crops, operation timing and labour use for a particular situation can be calculated. This may be used to evaluate, for example, the costs of changes to farming systems or specific operations. One example of tactical decision support is



One screen from the ARABLE Farm Model Program – showing some of the variables included in the program. Several of the Silsoe derived programs are now available in translation.

the use of a model to predict the optimum timing of particular operations within a season.

A second order problem is that most of the programs derived from experimental data are not interactive, nor designed for use by non–specialists. The Information Technology Group at Silsoe has developed a range of user friendly interactive microcomputer programs covering topics that range from the evaluation of dairy cow feeding systems to predicting tractor work rates; and from comparison of irrigation systems to the effects of different applications of nitrogen and fungicide on final yield and disease in a cereal crop.

A waste engineering expert system (WEES) has been developed with ADAS to incorporate research results and expertise from several organisations. It provides cost–effective solutions to reduce common environmental hazards arising from improper storage and disposal of slurry and includes technical and financial analysis.

The Silsoe Group have several overseas collaborations and contacts and several of their programs have been translated. For example, a collaborative study with CEMAGREF is working to improve ARABLE – a program on the planning of cropping and other operations.

BASICS FOR BIOTECHNOLOGY

The elegant simplicity of many biotechnological protocols is deceptive. Although strategies for transferring genes and modulating their expression can be readily designed in principle, many technical difficulties still remain. Here we report on three examples of how AFRC research is tackling these problems.

Understanding the role of molecular chaperones

There is already considerable commercial interest in expressing genes for useful proteins in heterologous systems – e.g. using a plant or bacterium as a factory for synthesis of the product. Such systems offer several advantages – low cost, high yields, ease of product purification, and ease of genetic manipulation. There are also direct applications, for example, the production of anti–viral agents in transgenic plants could protect them from viral diseases.

Such strategies are based on the assumption that transfer of the genes coding for the product, together with their regulatory DNA sequences, is all that is needed to yield a functional product. This assumes that sequences of amino acids automatically fold up and assemble themselves correctly into proteins. But recent research, much of it funded by the SERC, has necessitated a rethink on protein self–assembly. Many proteins require helper or chaperone proteins for their correct folding and assembly.

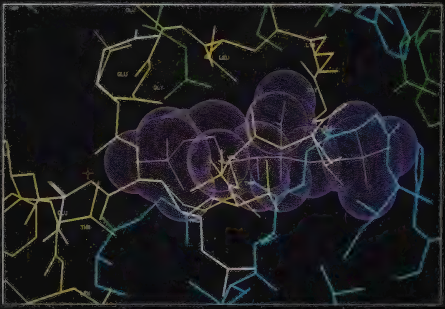
An AFRC–funded collaborative project between scientists at the University of Warwick and Birkbeck College, London is exploring the three–dimensional structure of chaperonins – a subgroup of chaperones – found in bacteria, mitochondria and plastids. Chaperonins are believed to work by preventing partially folded or unassembled protein units from incorrect folding or from aggregating and precipitating. They appear to achieve this by non–covalent binding to interactive surfaces of the

Chaperones for rubisco

Rubisco is the chloroplast enzyme in plants which fixes carbon in photosynthesis. It is notoriously inefficient and a prime candidate for improvement by genetic engineering – which requires an *in vivo* expression system. But genes coding for rubisco do not produce a functional enzyme in the bacterium *E. coli* It seems that the genes are read correctly, but that the protein does not assemble properly.

Plant rubisco is made up of eight large and eight small subunits. Its assembly requires the intervention of two chaperonins (cpn 60 and cpn 10). Early in assembly, the large subunits interact with cpn 60, forming a stable intermediate; later, cpn 10 is believed to be involved in bringing together the large and small subunits.

AFRC–funded research at the University of Warwick and Birkbeck College, London is investigating the structures of these chaperonins with and without bound rubisco subunits. The complex formed by cpn 60 and the large subunits is being crystallised for X-ray diffraction analysis at Birkbeck. The cpn 60s from bacteria and chloroplasts have a "double doughnut" structure consisting of two rings of seven subunits each, with a central hole. The cpn 10 of *E. coli* is a single ring of seven. One aim is to identify the putative cpn 10 of chloroplasts.



Catalytic heart of rubisco. Targeted improvement of its catalytic properties could increase carbon uptake by crops. (This structure of a cyanobacterial enzyme was modelled at IACR using software from information on the spinach enzyme provided by Swedish scientists.)

protein which are exposed only in the early stages of folding. One aim of the AFRC project is to understand how chaperonins recognise this interactive surface.

The research has practical implications for the design of gene transfer and genetic engineering protocols. For example, it may sometimes be necessary to transfer one or more chaperone genes together with the target gene in order to ensure correct folding of the gene product in its new environment.

Remodelling plant metabolic pathways

Many pharmaceuticals and natural food colouring or flavour compounds are metabolites of plants. At the AFRC Institute of Food Research (IFR) a three–fold strategy is being developed to increase yields of such valuable compounds using genetically transformed root and shoot cultures. The first step is to identify the metabolic steps in product biosynthesis and the enzymes involved; the second is to elucidate how each step is regulated and to identify control–points that govern flux through the pathway; and the third is to use genetic manipulation to increase product accumulation.

The IFR scientists are studying alkaloid biosynthesis in the model plant, tobacco *(Nicotiana)* and the pharmaceutically important Thorn Apple *(Datura stramonium)*. The activity of the enzyme putrescine methyl transferase (PMT) is a major control-point in both species. The genes coding for PMT and other important enzymes in the pathway are being identified using complementary DNA probes. Manipulating their levels of expression is one strategy for modulating flux through the pathway. Another option might be the insertion of genes for additional enzymes. The IFR researchers have inserted a yeast gene coding for ornithine decarboxylase into tobacco roots and shown that this increases accumulation of one of the pathway products, nicotine.

Techniques for tagging plant genes

When useful genes for manipulation or transfer have been identified, the next step is to isolate them. If this is not immediately possible, an alternative is to tag the genes with a molecular marker. Gene "tagging" can mean two quite different things. A tag can be an easily detected gene that lies very close to a gene of interest (target gene). Such a tag can be used to monitor the inheritance of the target gene by plant breeders. Still the most conveniently employed markers are proteins, and at the Cambridge Laboratory (IPSR) the gene controlling a form of the enzyme endopeptidase has been found to be very closely linked to a gene for resistance to eyespot disease. Thus, the enzyme acts as a marker for resistance and its analysis by electrophoresis provides a rapid basis for selection.

Alternatively, the term "tagging" is applied to programmes in which transposons are used to inactivate target genes and facilitate their isolation. Transposons are mobile pieces of DNA capable of inserting themselves into the plant chromosome (creating a transposon mutation). They sometimes disable genes at the site of insertion, so the role and location of individual genes can be determined by a correlation of the site of transposon insertion with altered behaviour in the mutant. The gene can then be obtained from the transposon mutant by isolating the segment of DNA containing the transposon. This approach is being used in IPSR to identify and isolate genes (see pages 22–23) and at the University of Birmingham to identify genes that confer resistance to specific pathogens.

The Birmingham researchers are isolating an R gene from *Antirrhinum* which confers resistance to a specific race of *Antirrhinum* rust. They have produced plants which are susceptible to the disease, and whose progeny revert to resistance, in a manner consistent with the inactivation of this gene by a transposon. The next step is to probe extracted DNA from these plants with transposon sequences in order to identify the fragment bearing the transposon–inactivated R gene.

Mint flavour – transformed shoot cultures of *Mentha piperita* growing in a bio–reactor and producing flavour compounds.

IMPROVING THE PROTEIN COMPOSITION OF MILK

Attitudes to milk exemplify the change in emphasis from quantity to quality that has characterised market demands in agricultural and food production in the UK in recent years. Clearly, there are many potential benefits for industry and the consumer in being able to modulate the protein content of milk and the functional properties of the proteins.

The composition of milk produced by the dairy cow changes during lactation. Whilst the hormonal control of milk biosynthesis in the lactating gland is reasonably well understood, the regulation of nutrient supply to the gland and the integration of mammary metabolism with other metabolic processes are less so. A new programme, initiated jointly by the SOAFD-funded Rowett Research Institute and the AFRC Institute of Grassland and Environmental Research, and funded jointly by MAFF, BP Nutrition, the Milk Marketing Board, AFRC and SOAFD is attempting to investigate how protein content of milk is regulated. The study will focus particularly on the regulation of nutrient uptake by the lactating gland and on liver metabolism with the ultimate aim of constructing a mechanistic model of the factors that influence milk yield and composition as an aid to identifying nutritional strategies for the manipulation of milk composition.

Another approach is based on developing a better understanding of the expression of milk protein genes and their regulation. This basic research into gene expression and regulation in the mammary gland could also provide new insights into aberrant behaviour associated with breast cancer. Scientists at the AFRC Institute of Animal

Pharmaceutical proteins in milk

Scientists at IAPGR were the first to demonstrate that human proteins of medical importance could be produced in the milk of sheep. This is achieved by introducing into the host animal special constructs of the human genes, i.e. the gene coding for the protein and those DNA sequences necessary for its regulation and targeted expression in the mammary tissues.

The essential human blood clotting protein, Factor IX, and the elastase inhibitor, α1–antitrypsin (which has potential for treating forms of the degenerative lung disorder emphysema caused by a genetic defect, and may also have application in relieving some symptoms of cystic fibrosis) have been successfully produced in the milk of transgenic lines of sheep and mice. But initially yields of these proteins were low.

Emphasis at IAPGR has switched to improving the design of the gene constructs so that more of the gene product is produced. Working with the mouse system, the IAPGR scientists have been able to increase protein yields for α1–antitrypsin by more than a hundred–fold. They have done this by including introns in the gene constructs. Introns are sequences of DNA which had previously been largely ignored and thought to be "unimportant". But it turns out that there are important regulatory DNA sequences within introns which are important in determining the extent to which a gene is expressed.

This work is being taken forward in collaboration with the private company, Pharmaceutical Proteins Ltd, which has produced sheep with the same intron-containing gene. One of these sheep has produced even larger amounts of α1–antitrypsin in its milk than the mice and this technology is now moving rapidly towards commercialisation.

A ewe which produces high levels of α1-antitrypsin in her milk, with her lambs, one of which is also transgenic for this protein.
(Photo: Pharmaceutical Proteins Ltd.)

Physiology and Genetics Research (IAPGR) at Roslin have shown that mice can be persuaded to produce a "foreign" protein, i.e. one from another species, in their milk without any side effects. This is achieved by introducing the gene for the foreign protein and directing its expression to the mouse mammary gland. However, although the mouse may produce large amounts of this protein so that it comprises about 50% of the total protein content of the milk, that total remains constant – the effect is a substitution of proteins, not an increase in overall protein content.

Two strategies for genetic manipulation of milk proteins are envisaged. One is to use genetic engineering techniques to modulate the performance of individual proteins. The caseins are an important group of milk proteins. They form structures known as micelles which influence the cheesemaking properties of the milk. Micelle structure depends on casein phosphorylation, which in turn depends on the amino acid sequence of the protein, so directed changes in the casein gene could improve the cheesemaking properties of the milk. Before gene modification can be attempted, more needs to be known about how the structure of the caseins determines their functionality. This is being explored in collaboration with scientists at the SOAFD–funded Hannah Research Institute. The proteins of milk also influence its heat stability, and they bind calcium – both are important attributes that could be amenable to modification by genetic manipulation. The second approach is to alter the protein profile of the milk, i.e. the types of proteins present. This could improve digestibility and enhance milk and milk product formulations to meet special dietary requirements such as those for infants. Transgenic animal models are necessary to study the expression of genes for the milk proteins because it has proved impossible to achieve their expression efficiently in cells cultured *in vitro* – a functioning mammary gland is required.

A major sheep whey protein in mouse milk. The proteins in milk can be separated as they migrate through a gel under the influence of an electric field.
From left to right:
1. & 6-8. Purified β–lactoglobulin;
2. sheep milk proteins;
3. transgenic mouse milk proteins (high expressing line);
4. transgenic mouse milk proteins (low expressing line);
5. control mouse milk proteins.
Channels 3 and 4 show the β–lactoglobulin in the milk of mice carrying the sheep gene for this protein.

β–lactoglobulin (BLG) is the major whey protein of ruminants. At IAPGR, the sheep gene for BLG, and those DNA sequences essential for its expression specifically in mammary tissue, have been transferred into mice. This approach is also being used to investigate the factors that regulate these genes *in vivo.* In some of the mouse lines, the concentration of BLG was more than five fold higher than that found in sheep. The BLG protein produced in these mice appears entirely normal, and its high level of production has no deleterious effects on the suckling mother or her pups. This demonstrates the large alterations to milk protein composition that might be available through genetic manipulation.

It is obviously essential for the long term aim of being able to improve milk protein composition by introducing new genes into cattle lines, that the foreign gene is regulated normally. There is evidence from IAPGR that this is indeed the case. The levels of BLG and some of the caseins produced by a ewe are not constant. They gradually increase during gestation from a low basal level, to reach a maximum shortly after the start of lactation, before falling back to the basal level by the end of lactation. Mice carrying the sheep BLG gene follow the same pattern of expression, suggesting that their hormones trigger expression in a similar manner to those of the sheep.

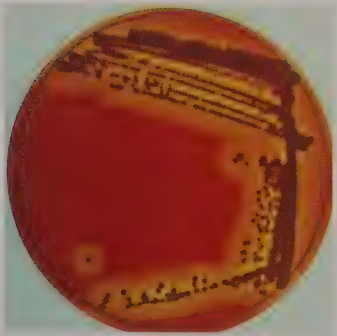
GENETIC ENGINEERING OF FORAGE DIGESTION

Microbial cellulases and hemicellulases, produced by organisms which inhabit the digestive tract, play a vital role in the digestive process of ruminant and non–ruminant herbivores by degrading the major polysaccharides of plant cell walls. In an AFRC Linked Research Group programme, scientists at the AFRC Institute of Animal Physiology and Genetics Research (IAPGR) at Babraham, in collaboration with scientists at the University of Newcastle-upon-Tyne, are investigating the biochemistry and molecular biology of these enzymes. The manipulation of cellulases and hemicellulases by means of recombinant DNA techniques holds enormous potential, not just for agriculture, but also for future industrial processes using plant biomass as a source of biofuels, bulk organics or fine chemicals.

Compared with other components of the ruminant diet, cell wall polysaccharides are digested relatively slowly and incompletely by microorganisms which reside in the forestomach or rumen. An improvement in this aspect of rumen function might be achieved by introducing the capacity to digest cellulose and hemicellulose into previously non–cellulolytic bacteria. One approach is to use extrachromosomal plasmid DNA as a vehicle for carrying a foreign cellulase gene, and electroporation – a process in which pulses of high voltage electricity are used to generate transient pores in the cell membrane through which pieces of DNA can pass – as a means of introducing the new gene to a suitable recipient. In this way, IAPGR scientists with their Newcastle colleagues have successfully transferred a cellulase gene from *Clostridium thermocellum* into *Lactobacillus plantarum*, a non–cellulolytic organism commonly used as an inoculant to promote rapid fermentation and development of acid conditions during the preservation of forages by ensiling. Under some circumstances, effectiveness of the inoculant is limited by the availability of suitable substrates. The object of the IAPGR work is to make *L. plantarum* more effective by equipping it with the enzymes necessary to degrade at least part of the structural polysaccharides in forages and so provide sugars ready for fermentation. A similar approach will be applied to non-cellulolytic rumen bacteria.

An alternative strategy for modifying rumen function might be to amplify the number of genes coding for naturally –

MODIFYING DIGESTIVE FUNCTION IN FARM LIVESTOCK BY TISSUE–SPECIFIC EXPRESSION OF MICROBIAL GENES.



A bacterial gene, shown here expressing cellulase activity in *Escherichia coli*, will be fused to appropriate regulatory and secretory signals and inserted into transgenic mice to obtain pancreas-specific expression.

Once the technology has been developed in mice, transgenic pigs secreting bacterial cellulase/xylanase into the small intestine could be produced. These animals would derive more energy from plant tissue, and could use the β-glucan component of barley-based diets more efficiently.

occurring cellulase activity or to modify the enzymes by protein engineering. This could help ruminants to make better use of highly fibrous diets and reduce reliance on high energy grain–based feeds. Low-cost recombinant enzymes – synthesised by laboratory bacteria harbouring cloned genes – or genetically engineered polysaccharide hydrolases with improved properties could also be used *in vitro* to pre–treat forages as a means of improving the nutritional value of low quality feeds. In the long term, perhaps the most exciting prospect is the introduction of bacterial cellulase genes into the germ line of simple–stomached animals such as the pig. Tissue-specific expression of the encoded proteins in the pancreas and their secretion into the small intestine would allow these animals to make more efficient use of the β–glucan component of cereal-based diets, and might eventually mean that they could be fed a higher proportion of forage.

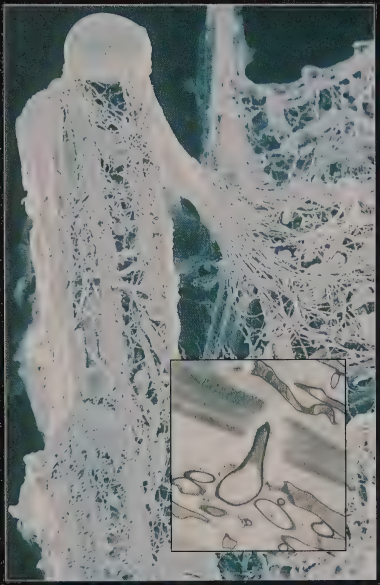
The complete hydrolysis of cellulose to glucose involves the cooperative action of three different enzymes: endo–β–1,4 glucanase; exo–β–1,4–glucanase; and β–glucosidase. Similarly, xylan degradation is effected by endo–β–1, 4–xylanase, β–xylosidase and xylobiase. Cellulolytic microbes are frequently able to hydrolyse xylan also and often produce multiple isomeric forms of the above enzymes, encoded by multiple genes and sometimes organised in multiprotein aggregates. Scientists working at IAPGR and in Newcastle have isolated genes coding for a number of key enzymes involved in cellulose and hemicellulose hydrolysis from both aerobic and anaerobic cellulolytic bacteria, and have determined the biochemical properties and primary structure of the encoded proteins. In general, the genes are widely dispersed on the bacterial chromosome and are not organised in functional clusters. Furthermore, the construction of hybrid proteins containing domains from different parent enzymes has established that cellulases and xylanases from different organisms can conform to a similar pattern of molecular architecture, in which the catalytic domain is distinct from a non–catalytic cellulose binding domain which functions quite independently and is highly conserved with respect to primary structure.

A major future aim of the IAPGR/ Newcastle group will be to continue to use recombinant DNA techniques for evaluating the relationship between structure and function in cellulases and hemicellulases; some of this work will be conducted in collaboration with the SOAFD-funded Rowett Research Institute. Specifically, they will examine the role of the non–catalytic domains in multidomain enzymes, as their manipulation might be important for constructing hybrid enzymes with improved properties. Optimisation of the effects of tissue–specific expression of a bacterial cellulase gene in transgenic animals may require that other cellulase–related enzymes be produced within the digestive tract. With this object in mind, the groups will study the synthesis and secretion of cellulases and xylanases by cultured epithelial cells.

Anaerobic fungi in ruminant digestion

As well as cellulolytic bacteria, the rumen also contains populations of anaerobic fungi that digest cellulose. The complex life cycles of these fungi and their key ecological characteristics and enzyme systems are being investigated at the AFRC Institute of Grassland and Environmental Research.

There is evidence that the physiology of the fungi, and in particular, their ability to penetrate deep within plant matter, contributes significantly to their cellulolytic activity and that they perform a vital role in opening-up particle structures to enzymic attack by the other rumen microorganisms. Different fungi are being ranked according to their ability to degrade plant cell walls. One aim of the IGER work is to characterise the enzymes involved and compare them with commercially–useful cellulases from other micro-organisms.



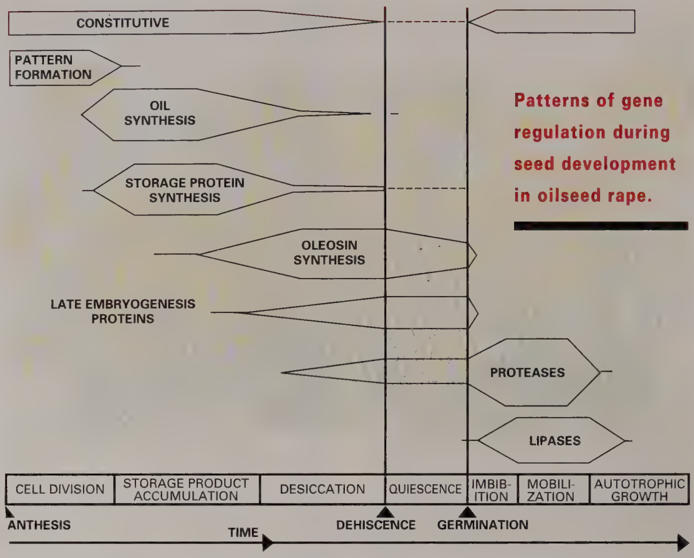
Straw particles colonised by anaerobic fungus.

Inset: rhizoids of the fungus penetrating and digesting the plant cell wall.

OILSEEDS

Oilseed crops could provide an alternative for some products currently derived from non–renewable fossil fuels.

The industrial usefulness of seed oils depends on their physical and chemical properties, which in turn depend on their fatty acid composition. Unfortunately, many of the oilseed plants grown in the UK lack the enzymes to make some of the most valuable fatty acids, including very long chain fatty acids, which are important in the manufacture of plastics, lubricants, pharmaceuticals and other high–value products. If the genes for these enzymes could be engineered into successful crops such as rape, the value of oilseed products would be increased and they could be tailored for specific industrial purposes.



Patterns of gene regulation during seed development in oilseed rape.

The UK grows about 350,000 hectares of oilseed rape, but oilseed crops remain an under-utilised agricultural resource.

But before new genes can be introduced or resident genes modified, more needs to be known about the synthesis of oils and proteins in oilseeds, and its regulation. Scientists at the Cambridge Laboratory of the AFRC Institute of Plant Science Research, including members of the AFRC–supported Oilseeds Research Group formerly at the University of Durham, are studying the accumulation of storage products in oilseeds and its regulation. One objective is to identify genes that control economically important characteristics.

About half of the mass of a mature seed from oilseed rape is storage oils, and about 25% is storage proteins of which napin and cruciferin are major components. A further 6% is accounted for by a class of proteins, the oleosins, recently discovered by the Durham group. Oleosins have industrial potential in their own right as efficient emulsifiers.

Storage products accumulate mainly over a period of about four weeks before the seed dehydrates, although some continue to be synthesised during desiccation. The oils start to accumulate about a week before napin and cruciferin: oleosin synthesis occurs only during de-hydration. To test whether this pattern of accumulation results from a sequential switching–on of different genes for the different synthetic pathways, the IPSR scientists have measured levels of messenger RNA – the transcript of the genetic material which codes for proteins – during seed development. They found that the message for the storage proteins did indeed appear earlier than that for the oleosins. This indicates that accumulation of these proteins is regulated at the level of gene transcription. Nucleic acid probes are now being used to find the regulatory factors involved. In another approach, the expression of individual genes is being selectively blocked using antisense genes – of particular interest is how the elimination of one class of storage proteins affects synthesis and accumulation of the others.

"... Understanding the physiological and biochemical consequences of environmental changes is essential if we are to be able to develop sound strategies for agriculture and food production in the future .."

FRONTIERS IN

Global Environmental Change

42-43 *Animal welfare and production in a changing climate*

44-48 *Equipping plants for new environmental challenges*

49 *Preparing for new patterns of pest and disease attack*

50 *African horse sickness and bluetongue disease*

ANIMAL WELFARE AND PRODUCTION IN A CHANGING CLIMATE

Changes in environmental temperature might be expected to influence animal production indirectly, for example, through the availability and composition of plant–based feedstuffs. However, there are also direct effects, such as those on animal growth and reproduction. If we are to be able to develop strategies for maintaining productivity and enhancing animal welfare under changing climatic scenarios, we need to know more about the fundamental physiological and biochemical mechanisms by which animals respond to changes in environmental factors such as temperature.

Scientists at the AFRC Institute of Animal Physiology and Genetics Research (IAPGR) Edinburgh Research Station are investigating the influence of environmental conditions on aspects of poultry husbandry and management.

Diet is a good place to start because energy from feed is the source of metabolic heat production in poultry, and because feed intake decreases at higher environmental temperatures. Precisely how much heat is generated by a diet depends on its composition, different ingredients having different thermogenic properties. It should be possible, in principle, to design diets that provide the correct nutritional input as temperature (and consequently, metabolic energy requirements and feed intake) changes.

This approach is being pursued by IAPGR scientists who have developed a rapid bioassay system for measuring metabolisable energy of feedstuffs and a calorimetry system for measuring thermogenic effects. These systems allow them to evaluate the contribution of individual ingredients, and offer the potential of tailoring diets for particular climatic conditions. Decreasing the thermogenic effect of a diet might be used to compensate for higher environmental temperature; or if extensification or welfare considerations have resulted in birds moving to cooler conditions, at lower stocking densities, increased thermogenic input from their feed might be beneficial.

This strain of chicken expresses the "naked neck gene" a feathering defect. The strain is allegedly more heat tolerant than others, and adaptations in its metabolism could provide important clues for strategies to increase heat tolerance in commercial flocks.

Thermal load

In research aimed at identifying optimal environmental conditions which meet the birds' welfare needs, the concept of "thermal load" is important. This includes not only temperature, but factors such as humidity which influences evaporative heat exchange.

From these studies a single index, apparent equivalent temperature, has been developed to allow comparison of different still air situations. This approach has been used in collaboration with the AFRC Silsoe Research Institute to study the thermal environment inside poultry transporters – recommendations based on physiological studies have helped to form the basis of a new code of practice.

Although chickens that are habitually exposed to high environmental temperatures eat less feed, this alone does not account for their significantly slower growth rate. Indeed, research at IAPGR has shown that if feed intake in birds kept at "neutral" temperatures is reduced to that of birds living at high temperatures, they do not show the same reduction in growth rate – suggesting that thermal stress *per se* slows growth. Alterations in the endocrine control of growth are implicated.

Growth hormone (GH) from the pituitary gland stimulates conversion of one thyroid hormone, thyroxine or T4, into another, tri–iodothyronine (T3) mainly in the liver. Research at IAPGR suggests that the slow growth observed in birds exposed to high temperatures results from an impairment in this process. In such birds, stimulation of the conversion of T4 to T3 by GH is greatly attenuated, effectively dissociating the GH control. This effect is proportional to the increase in heat load experienced by the birds.

Dissociation of GH control, observed in genetic disorders associated with slow growth, may be mediated by changes in the affinity or numbers of growth hormone receptors. This is one of several areas currently being explored at IAPGR. In the long term, it might be desirable to select genetically for strains with enhanced heat tolerance. A strain that is reputed to grow more efficiently than others at high temperatures is currently being examined. Circulating levels of T3, T4 and GH are being measured in these birds at different heat loads and compared with those of apparently more heat–sensitive strains.

One solution to the problems of low growth at high temperatures is to move birds to higher altitudes where temperature and humidity are lower. This approach is used, for example, in South Africa and South America.

However, altitude effects, specifically reduced oxygen partial pressure, can be detrimental to the health of the birds. Air quality is another factor important in minimising stress. Poultry accommodation should, therefore, have adequate ventilation. The aim should be to supply fresh air and eliminate carbon dioxide and other noxious gases such as ammonia. Poor ventilation is associated with increased lung disorders.

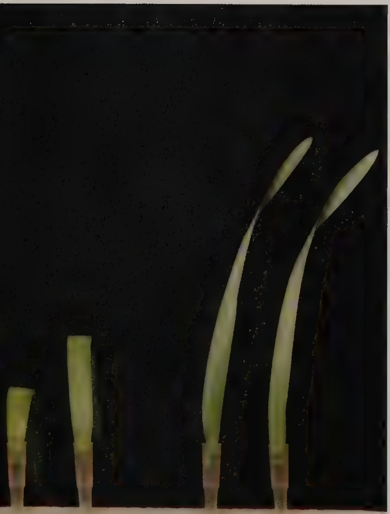
Climate change might influence susceptibility to disease in some situations. Hot and cold weather can cause significant changes in the immune systems of animals, affecting both antibody and cell-mediated responses. The welfare and health implications are being investigated at IAPGR, with particular attention on cardiopulmonary dysfunction in broilers in relation to low oxygen tension.

Part of the computer-controlled calorimetry system.

EQUIPPING PLANTS FOR NEW ENVIRONMENTAL CHALLENGES

Plants have developed a variety of mechanisms for coping with environmental stresses such as extremes of temperature and periods of drought. An understanding of how these mechanisms work and are regulated might allow the engineering of genes conferring environmental tolerance into major crop species. This would allow their global distribution to be increased, for example, into currently hostile environments, and could be used to equip crops to grow efficiently under the more diverse climatic conditions that might result from global environmental changes.

AFRC supports a wide ranging programme of research on plant responses to environmental stresses – including identification of physiological responses and their underlying molecular biology, and the development of hybrids with enhanced stress–resistance.

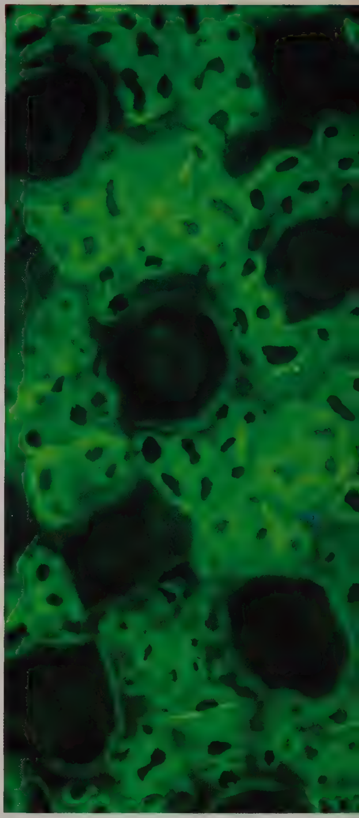


Barley plants with a genetic defect affecting the hormone abscisic acid wilt more rapidly than others under drought conditions.

Drought resistance

The development of stomata, the pores on the underside of leaves which allow uptake of CO_2 and loss of water through transpiration, was crucial in the evolutionary conquest of terrestrial environments – so it is not surprising that stomatal regulation provides important clues about plant responses to water–deprivation.

At Bristol Polytechnic the role of the plant hormone, abscisic acid (ABA), in protecting against water stress is being explored using mutants of *Arabidopsis thaliana*. ABA is synthesised in mesophyll cells in response to declining water potential. It is transported to the epidermal cells where it stimulates closure of the stomata by triggering shrinkage of the guard cells that line the pore, thus switching off transpiration. By comparing two different mutants of *A. thaliana* – one unable to synthesise adequate amounts of ABA, and the other insensitive to ABA, it is possible to discriminate between responses due solely to water stress and those due to induction of ABA. The aim is to identify genes which are induced by water stress to synthesise ABA, and those subsequently induced by the ABA. So far, in collaborative studies with the AFRC Institute of Arable Crops Research, it has been shown that at least one polypeptide is synthesised in response to ABA and one in response to water stress *per se*.



The stomatal pores on leaves are important in regulating water loss. Collaborative research between Bristol Polytechnic, the University of Leeds and the John Innes Institute (IPSR) is developing antibodies to probe the receptors on different cells of the plant epidermis. Here, the epidermis of *Commelina communis* is stained with a fluorescent monoclonal antibody, developed at the John Innes Institute, which binds to cells other than guard cells and their subsidiary cells.

The biochemical pathways by which guard cells receive and respond to signals such as ABA is being studied by researchers at the University of Oxford in collaboration with a group at the University of Edinburgh. Signal transduction via calcium is implicated from sophisticated imaging techniques used to visualise free calcium ion levels. Cellular levels are normally low, but respond to several closing stimuli such as ABA. Labelling techniques are being used to identify the calcium transport and binding proteins involved and their effects on response elements such as ion pumps in the plasma membrane.

As well as its effects on stomata, ABA also induces synthesis of a family of proteins which may protect desiccating seeds from the effects of dehydration. The genetic regulation of these dehydrins is being elucidated at the University of Leeds. The most abundant protein in the dry wheat embryo is the Em polypeptide. It is the product of a family of about a dozen genes, and is one of several ABA–regulated proteins thought to protect the cellular constituents from denaturation during desiccation. Interestingly, expression of these genes can be triggered by ABA or water stress in germinating seeds, and they may play a role in protecting vulnerable seeds from drought. The Leeds group are using DNA sequencing to identify regulatory elements that control transcription of the Em genes, and are studying transient promoter activity in plants. One aim is to identify the transcription proteins which interact with these regulatory elements to switch on Em expression.

Rice plants accumulate ABA very rapidly in response to water–deprivation: they can increase ABA concentration by over 25–fold in two hours. Research in the AFRC Institute of Plant Science Research (IPSR) has shown that three proteins are synthesised in rice during the first thirty minutes of drought stress as a result of *de novo* transcription of drought–activated genes.

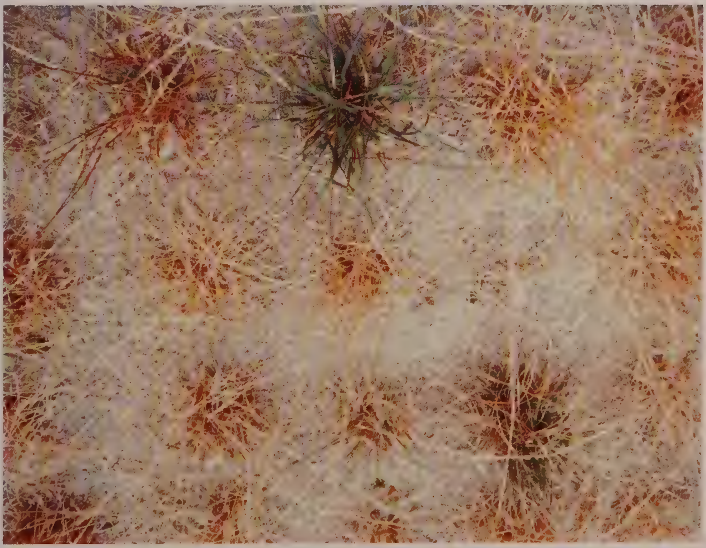
Studies at Horticulture Research International and at the University of Lancaster have shown that ABA transported in the xylem sap from the roots to the leaves is important in regulating both stomatal aperture and leaf expansion, and hence in reducing crop water use, when rainfall is inadequate.

In many cases, tolerance to environmental stresses resides in distant or wild relatives of crop plants. In such cases straightforward crossing may be impossible because of genetic incompatibility, or because of the introduction of undesirable genes as well as those for stress–resistance. At the AFRC Institute of Grassland and Environmental Research (IGER) wide crossing techniques are being used to increase drought and cold tolerance in ryegrass, the basis of most productive pasture in Britain, by introducing genes from fescues.

Fertile hybrids of a range of ryegrass and fescue species can be produced using embryo culture and chromosome doubling. Some may be of direct use as new varieties. For example, the tetraploid varieties Elmet and Prior, produced by crossing meadow fescue with Italian ryegrass and perennial ryegrass respectively, perform well under the harsh conditions of Canada or the American mid-west.

Hybrids between ryegrass and tall fescue have proved difficult to stabilise. However, they can act as genetic bridges for transferring useful genes between species (introgression). Backcrossing hybrids into ryegrass could result in varieties with better drought tolerance and winter hardiness. Backcrossing into tall fescue could produce tall fescue varieties with improved quality.

Ryegrass can be made more drought resistant by introducing genes from the fescues: *Festuca* X *Lolium* hybrids surviving after 3 months drought under a rain shelter.



Wide crossing also offers ways of introducing desirable characteristics into brassicas such as oilseed rape. In IPSR, interspecific hybridisation between *Brassica insularis* a wild drought–resistant (and to some extent pest and disease–resistant) species and *B. rapa* has produced synthetic rape plants which can be crossed with oilseed rape varieties to introduce these desirable genes.

Flooding tolerance

At the other extreme from problems of drought, are those caused by water-logged soils. Again, some wild relatives contain useful genes for adaptation to flooding. In IPSR, wide crossing is being explored as a means of introducing genes from the flooding–tolerant *Elytrigia repens (Agropyron repens)* into varieties of wheat.

Studies of the action of the plant hormones, abscisic acid and ethylene, in plant adaptation to flooding and submergence are being made at IACR. Species, such as rice, are able to shorten the duration of total submergence by rapid underwater extension promoted by ethylene, while others, such as maize and wheat, rapidly develop internal cavities in response to ethylene that help aerate the plant. Abscisic acid has proved important in preserving leaf hydration when only the soil is flooded. Identifying the physiological and molecular mechanisms of these and related phenomena will underpin future efforts to improve crop resilience to increased flooding if UK winters become wetter and the summers more stormy.

Salt tolerance

Where global warming occurs it might be expected to increase the need for irrigation. This brings an additional problem because irrigation water contains large quantities of dissolved salts and almost always results in secondary salinisation of the soil. Cereal crops are generally sensitive to salt levels but some wild relatives of wheat, including the sand couch grass *Thinopyrum bessarabicum*, are much more tolerant.

In IPSR, hybrids of wheat/*T. bessarabicum* have been produced which are able to survive and set seed in up to half strength sea water, well above the salt levels encountered in irrigation water levels and far exceeding the threshold for normal wheat. Procedures used to create these hybrid lines allow differences in defined chromosomes to be correlated with difference in plant performance. Thus it has been possible to identify a single chromosome from *T. bessarabicum* which is associated with salt tolerance.

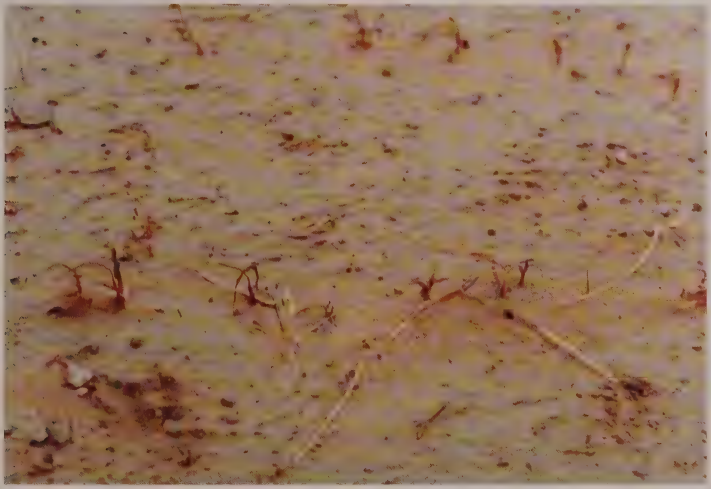
The mechanism of salt tolerance is unknown, but appears to involve the ability to exclude salt from young and sensitive tissues at the growing point of the plant.

Heat tolerance

In an analogous way to that in which drought induces production of dehydrins, heat–shock also induces a specific set of protective proteins. The heat–shock proteins (HSP) of different strains of millet are being studied at IGER as part of an investigation into the physiological, biochemical and molecular basis of thermotolerance.

Millet seedlings synthesise little protein when exposed to 50°C for two hours and cease growing when returned to normal growing conditions after this treatment. If the seedlings are kept at 45°C for thirty minutes prior to the 50°C treatment, not only does protein synthesis occur at the higher temperature, but the seedlings continue to grow. Thus, pre–treatment at 45°C induces HSP synthesis and confers protection against the higher temperature.

Salt tolerance has been introduced into wheats by forming hybrids with naturally tolerant wild species. This green labelled chromosome from a wild relative of wheat is associated with enhanced salt tolerance.



Strains of millet differ in their ability to withstand high temperature.
Top: **heat tolerant.**
Bottom: **heat sensitive.**

Field trials in India, in collaboration with International Crops Research Institute for the SemiArid Tropics, and funded by ODA, have compared the thermotolerance of over sixty different strains of millet. Although all produced HSPs, the extent of synthesis differed between varieties, as did the upper temperature limit for their synthesis. cDNA probes are being used to identify the genes coding for different HSPs. Antibody probes are also being used to investigate the cellular distribution of HSPs.

UK Global Environmental Research Office (GER)

The UK GER Office was established by all 5 Research Councils in July 1990. This initiative recognises the growing national and international interest in all aspects of global change and the need for the UK to coordinate responses to the research opportunities and challenges. The funding and support provided by all Research Councils is also a reflection of the inter-disciplinary approach required to address the many issues and problems which transcend the traditional disciplines within the natural and social sciences.

The primary role of the GER Office is to act as the focal point for provision and dissemination of information on UK and international science and policy developments. The Office played a key role in the preparation and publication of "Global Environmental Change: The UK Research Framework" (April 1991).

Crop responses to environmental changes

Studies on the responses of crops to increased levels of carbon dioxide, and changes in temperatures, provide a basis for forecasting how crops will perform under predicted future climatic scenarios. At the AFRC Institute of Arable Crops Research (IACR), simulation models have been developed which give important insights into how crops and environment interact. One model called AFRCWHEAT has been particularly useful in understanding the way in which crops of wheat grow and the factors of importance to their yield. It is being used, for example, to model the effects of temperature and elevated CO_2 on wheat yields.

Experimental studies of the physiological changes in wheat grown under different environmental conditions have focused on the effects of increased CO_2 (700 parts per million (ppm) by volume compared to 350) interacting with increased temperature (2 to 4°C above ambient and ambient) and also with nitrogen nutrition. Using specially constructed growth chambers at IACR Rothamsted to control CO_2 and temperature, doubling CO_2 and temperature increased dry matter and grain yield of spring wheat and winter wheat. Increased temperature decreased the effect of CO_2 on grain yield. Elevated CO_2 decreased nitrogen content in dry matter of spring wheat. In winter wheat photosynthesis is not affected by elevated CO_2.

Studies in oilseed rape and wheat of the activity of the chloroplast enzyme rubisco, which fixes CO_2, but which can also act as an oxygenase, show that higher temperatures favour the oxygenase reaction. This has important implications for the effect of climate change on growth.

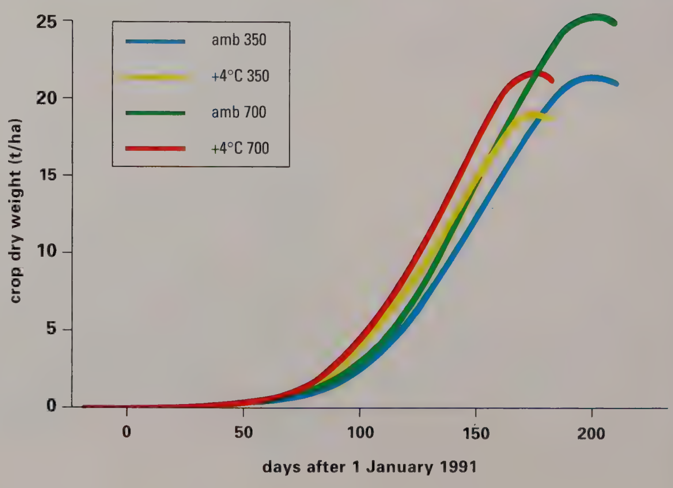
Studies at Horticulture Research International have revealed the importance of distinguishing between short and long-term CO_2 enrichment. Acclimation to high CO_2 acts to limit the yield dividend which might be expected from increases in atmospheric CO_2 and introduces uncertainty into models of the effects of future climate change.

The influence of increased CO_2 levels on the carbon and nitrogen economies of upland pasture grasses is also being investigated. A new project at the University of Manchester is comparing the response of different species of upland grass under controlled environments that differ in CO_2 and nitrogen regimes. One aim is to see whether environmental factors might influence the proportions of different species in a way that affects the pasture value, for example, by favouring an increase in less palatable species. The project will also examine the integration of nitrogen and carbon dioxide metabolism, and its implications for predicting plant responses to elevated CO_2.

Elevated CO_2

AFRC has recently launched a co-ordinated programme to examine the direct effect of elevated levels of CO_2 on the physiology, biochemistry and molecular and cellular biology of wheat plants. The new awards support research at the Universities of Reading, Essex and York, and Horticulture Research International, which complements, and in some cases is directly linked with, that of IACR.

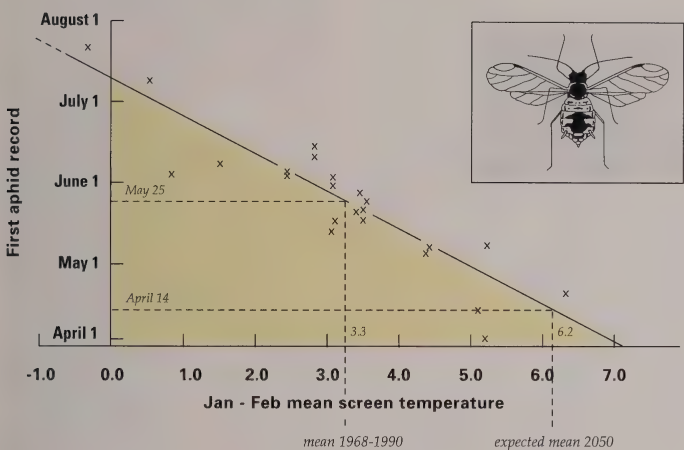
The programme considers three aspects – the mechanisms responsible for, and consequences of observed increases in leaf area in response to elevated CO_2; the mechanisms involved in the sometimes observed decrease in photosynthetic capacity (so called acclimation of photosynthesis) which follows periods at elevated CO_2; and the effects of elevated CO_2 on chloroplast development and the assembly of the photosynthetic apparatus.



Models of wheat growth at different temperatures and CO_2 levels. Units of CO_2 are 350 and 700 ppm by volume.

PREPARING FOR NEW PATTERNS OF PEST AND DISEASE ATTACK

Changes in climate have significant implications for the prevalence, severity and range of pests and diseases that attack crops.



By 2050, the aphid may appear 6 weeks earlier than at present

Data from insect surveys could help predict the consequences of climate change on pest abundance and migration. This example shows the "first trap" records of peach-potato aphid at Rothamsted.

Inset: Winged migrant of *Myzus persicae*.

Many important plant virus diseases are spread by aphids. Climatic changes that alter insect life cycles or increase opportunities for their survival through the winter will, therefore, alter the spread of disease. At IACR Rothamsted, a long–established survey of aphid abundance and migration in the UK, provides valuable insights into how these might change with predicted increases in temperature.

Early flights can cause severe damage to crops. This happened after the exceptionally mild January, February, March and May of 1990. That year, the times of first recorded flights of many aphid species including the peach–potato aphid, *Myzus persicae*, were among the earliest ever recorded. Predictions based on past records suggest that by the year 2050 *M. persicae* might appear 6 weeks earlier than at present. However, in 1990 there was an earlier than usual fall in aphid numbers, with less damage due to feeding. Research is underway to identify the interactions between winter weather, aphid survival and their natural predators.

Climate change might also alter the population dynamics of aphids. Several aphids of economic importance overwinter both as eggs (holocyclic clones) and as forms from entirely asexual (anholocyclic) clones. It is survival of the latter that mainly affects numbers of aphids early in the following summer. Evidence from IACR suggests that the balance of holocyclic and anholocyclic clones in populations of the bird–cherry aphid *Rhopalosiphum padi* varies between years. In autumns following mild winters, anholocyclic clones are more frequent, probably because they survive more successfully than after severe winters.

Models developed at Horticulture Research International can be used to predict the effects of climate changes on the field activity of carrot fly, beanseed fly, pollen beetles and large narcissus fly.

Aphid genotype/environment interactions are being studied at the Natural History Museum. The ability of an individual genetic constitution (genotype) to manifest different characteristics (phenotypic forms) as a result of modifications during development, is an important mechanism by which aphids adapt to environmental conditions. If for example, *M. persicae* are crowded together at birth they tend to develop into winged rather than wingless females. Temperature also influences the phenotype; how it does this and the implications for crop protection are being investigated.

Epidemiological studies at IACR have identified changes in patterns of diseases, such as *Septoria* infections of wheat, attributable to changes in the relative dominance and abundance of different species of pathogen; and how the relative importance of different diseases might alter with climatic changes.

AFRICAN HORSE SICKNESS AND BLUETONGUE DISEASE – TAKING HOLD IN A WARMER EUROPE?

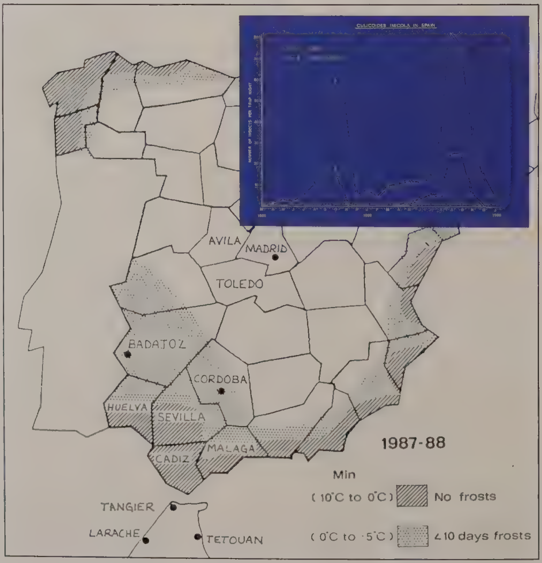
Persistently warm winters in southern Europe appear to have allowed the establishment and overwintering of insects that transmit two important and related viral diseases which are endemic in Africa – African horse sickness and bluetongue. Should climatic warming continue, these diseases might be expected to spread northwards, increasing their significance to the UK. Scientists at the AFRC Institute for Animal Health (IAH) are developing rapid diagnostic tests essential for programmes to control these diseases in countries where the problem already exists. They are also assessing any potential epidemiological risk to UK livestock.

African horse sickness is carried by biting midges of the genus *Culicoides*. It has been confirmed in Spain for the fourth successive year.

African horse sickness (AHS) is a devastating disease of horses, donkeys, mules and other equidae. In susceptible populations of horses, mortality from AHS infection can be as high as 95%. This disease has now been confirmed in Spain for the fourth successive year, and in Morocco for the second year – an unprecedented situation.

The virus that causes AHS is transmitted between animals by species of the biting midge of the genus *Culicoides*. Because adult midges can overwinter in frost–free areas, this vector is effectively "on the wing" all the year round in these areas. *C. imicola* was thought to be the only species carrying the virus in Spain, but recently the virus has also been isolated from two other species of *Culicoides* in Spain. They are *C. obsoletus* and *C. pulicaris*, which have a more northerly range than *C. imicola*, and are among the 48 resident species found in the UK. The vector competence of UK midges is now being evaluated.

Scientists at IAH have developed two types of immunological assays for use in AHS epidemiology and diagnosis. One, an indirect ELISA, is particularly suited for field work, and can be used to confirm clinical diagnosis within a day – it can also detect the virus in formalin–fixed insects collected in vector surveillance programmes. The other is a competitive ELISA that detects antibodies against AHS virus. It is particularly suited for screening large numbers of samples such as might be generated during vaccination campaigns.



Frost-free areas of Spain.

Inset: Seasonal prevalence of *C. imicola* in central and southern Spain.

C. imicola also carries bluetongue virus (BTV). Bluetongue disease is endemic in north and south America, Asia and Australia, as well as Africa, and it has made sporadic incursions into Spain, Portugal and Greece. In order to protect the UK sheep population it is essential that importation of ruminants or their products from BTV endemic areas should take place only when their freedom from infectious virus has been confirmed.

Collaborative research between scientists in the UK, USA, Canada and Australia, has led to the development of a competitive ELISA for diagnosis of the bluetongue virus. This is based on use of a BTV–group specific monoclonal antibody developed at IAH, and it is being proposed as an International Standard Test for import/export testing.

"... the new scientific opportunities, and hopefully a period of financial stability, create optimism and confidence for the AFRC .."

AFRC

Financial and other reports

52-56 *Financial Reports*

57-59 *International Report*

60-62 *Organisation and Human Resources*

63-64 *Council Committees*

Inside back cover *AFRS Institutes, Acronyms*

FINANCIAL REPORTS

For the financial year ending 31 March 1991, the expenditure of the Council and Council owned institutes was £141.4M.

The expenditure was financed from the following sources:

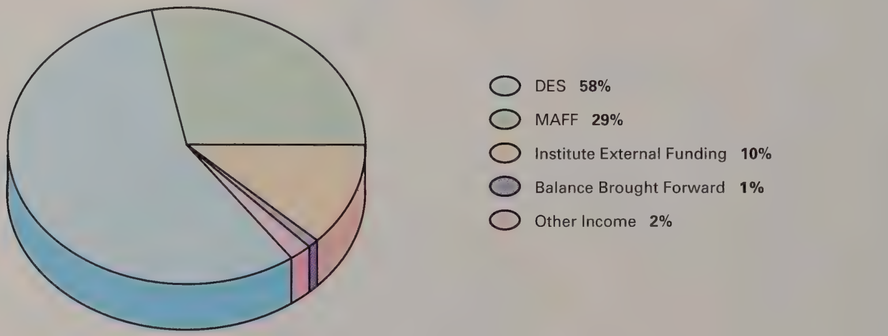
Science Budget grant-in-aid from the Department of Education and Science was ***£88.4M*** *(net of capital receipts) and commissioned research from the Ministry of Agriculture, Fisheries and Food amounted to* ***£45.1M****.*

This major funding was augmented by further Council income totalling ***£6.7M*** *being mainly contract and other income from industry and Government organisation and capital receipts.*

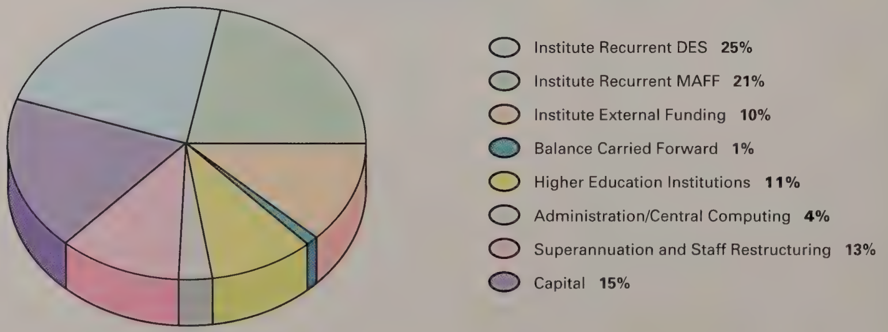
In addition to this income received by the Council, grant-aided institutes received outside funding estimated at ***£11.6M*** *from contracts and other agreements with industry, Government Departments, EC, Foundations and Trusts, etc. This income is included in the table on page 55.*

At the year end, the Council held a balance of ***£1.4M****, mainly in respect of capital commitments and commercial contracts.*

Total AFRC income for 1990/91 including external funding of AFRC grant-aided institutes (£153M)



Total AFRC expenditure for 1990/91 including external funding (£153M)

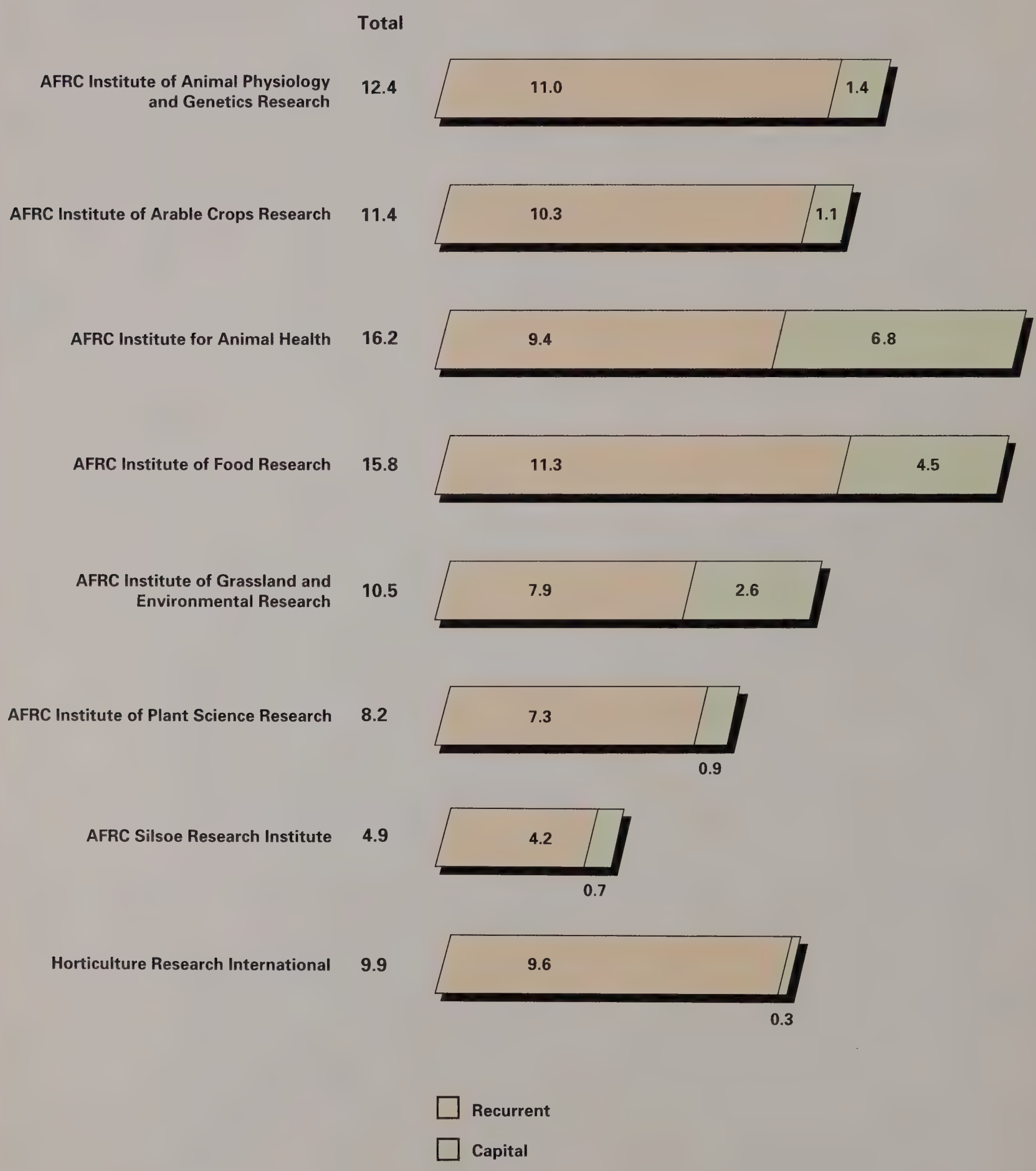


Summary of Income and Expenditure of the Council *year ended 31 March 1991*

	1989/90		**1990/91**	
	£000		£000	
Income				
Balance brought forward	256		1,179	
DES Grant-in-Aid	74,311		88,400	
MAFF Commissions	45,979		45,105 *	
Council Institutes and Units	5,281		5,692	
Capital receipts/Other income	3,916		989	
Total Income *(including balance brought forward)*		*129,743*		***141,365***
Expenditure				
Recurrent Expenditure				
Council and Grant-aided Institutes	72,017		74,499	
Research Grants to HEIs	15,001		14,699	
Postgraduate Training Awards	1,263		1,556	
Administrative and Central Computing Costs	6,435		6,578	
Superannuation and Staff Restructuring Costs	15,262		19,837	
Total Recurrent Expenditure		*109,978*		***117,169***
Capital Expenditure				
Land and Buildings	10,090		17,042	
Capital Equipment	8,496		5,735	
Total Capital Expenditure		*18,586*		***22,777***
Balance Carried Forward		*1,179*		***1,419***
Total Expenditure *(including balance carried forward)*		*129,743*		***141,365***

* *Excludes £537,000 paid to AFRC but transferred to the University of Bristol.*

Funding of Council and Grant-Aided Institutes (£M) 1990/91



EXTERNAL INCOME

The 1990/91 external income for research to Council and its institutes, i.e. from sources other than the Science Budget and MAFF Commissions, amounted to £16.5M. This compares with the 1989/90 total of £15.3M.

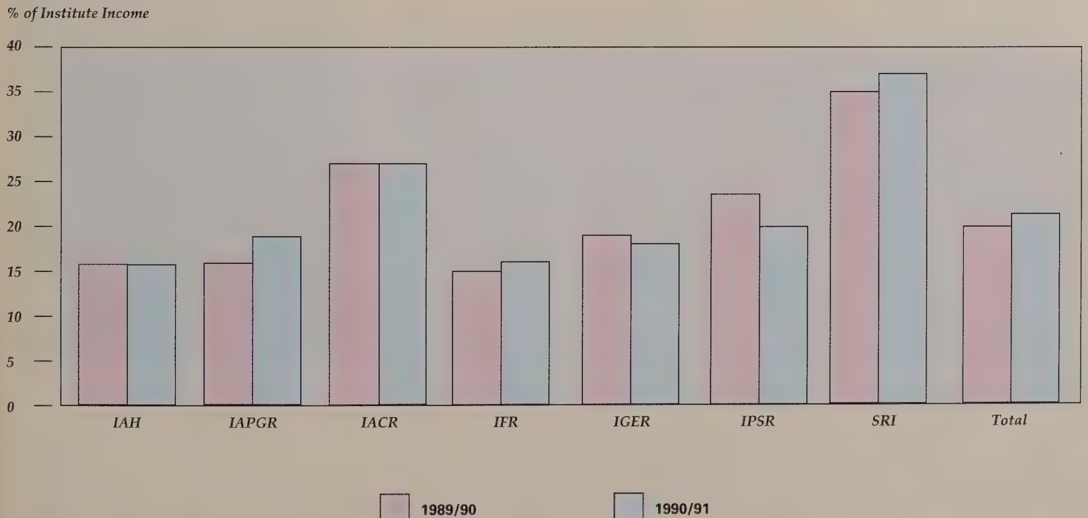
Income from Commercial and Other External Sources: 1990/91 Financial Year

Institute	Industry	Levy	Government Departments	MAFF OCF	Trusts etc.	EC	Total (£K)
IAH	864	0	429	0	254	268	1815
IAPGR	1368	59	652	150	299	83	2611
IACR	789	1291	1236	300	120	160	3896
IFR	1126	12	544	172	71	196	2121
IGER	587	309	402	388	0	61	1747
IPSR	1009	11	456	40	243	122	1881
SRI	750	30	1289	147	0	193	2409
TOTAL	***6493***	***1712***	***5008***	***1197***	***987***	***1083***	***16480***

Major industrial customers during 1990/91 included:

Agricultural Genetics Company Ltd
Animal Biotechnology Cambridge Ltd
BP International Ltd
British Technology Group
Ciba–Geigy Agrochemicals
Eli Lilly
Germinal Holdings
ICI plc
Intervet plc
Pitman–Moore
Rhone Poulenc Agrochemie
Semundo Ltd
Shell Research Ltd
British Sugar
Unilever plc

External Income at AFRC Institutes 1989/90 and 1990/1991 as % of Institute Income



It is Council policy that 25% of institutes' total recurrent income be derived from external sources by 1993/94, with a minimum target of 20% for each institute. Overall institutes have moved to 21% in 1990/91, compared with 20% in 1989/90.

LINK and AFRC Collaboration with Industry Scheme

In 1988, AFRC received £1M p.a. over a 5–year period for LINK purposes. In 1990/91, AFRC spent £950K on both LINK and its own scheme for collaboration with industry.

AFRC is co-sponsor of eight LINK programmes:

	AFRC commitment £M
Control of Plant and Microbial Metabolism	0.3
Protein Engineering	0.5
Eukaryotic Genetic Engineering	0.5
Molecular Sensors	0.25
Design of High Speed Machinery	0.5
Industrial Use of Crops	1.0
Agro–food Quality	0.5
Sustainable Farming Systems	0.45
TOTAL	***4.00***

AFRC's Collaboration with Industry Scheme exists in parallel with LINK and has been designed to strengthen industrial links and improve technology transfer. At least one industrial company and one science–based partner must be involved; the Government funds must be directed towards pre-competitive aspects of the collaboration; and industry must provide 50% of the costs. To date, 22 projects worth a total of £4.8M are in operation.

HEI Funding

AFRC expenditure on research grants during 1990/91 totalled £14.7M. AFRC is increasing the value of average ***AFRC Research Studentships*** to £5.0K p.a. with effect from October 1991. It is Council's intention to increase this to £5.5K and £6K in October 1992 and 1993 respectively.

Five researchers have been awarded ***AFRC Postdoctoral Fellowships*** to enable them to devote a significant period to full time research. The Fellowships are awarded for five years and the AFRC plans to establish 25 such Fellowships in the coming years.

The first ***AFRC Research Professorship*** was awarded to Professor Brian Follett FRS (University of Bristol). The award allows Professor Follett to pursue personal research on the hormonal events associated with photoperiodicity in animals.

The ***INRA/AFRC Fellowship Scheme*** was launched in 1990 under the five year agreement. Four scientists from INRA and four from AFRC have been awarded funds to enable exchange visits for periods of between six months and a year to work on collaborative projects.

AFRC administers two charitable funds that promote international exchanges of scientists. The ***Wain Fund*** provides grants for members of staff of UK universities to work overseas, and Fellowships for study abroad by academic staff of universities, including those who have recently completed postgraduate training and expect to enter a research career. Income from the fund for 1990/91 amounted to £36,676. Under this fund visits have been made to Australia, New Zealand, France, Hong Kong and the USA.

The ***Underwood Fund*** provides grants for distinguished overseas scientists to visit the UK and undertake research. This has supported visits of scientists from Australia, the USA, Poland, New Zealand, Japan, Israel and Chile. Income from the fund for 1990/91 was £53,138.

EXPENDITURE ON RESEARCH GRANTS SCHEME 1990/91

	£M
Responsive mode	7.66
Linked	2.19
Cooperative	0.12
Centre for Genome Research	1.30
Special Initiatives (e.g. Plant Molecular Biology)	3.43
TOTAL	***14.70***

INTERNATIONAL REPORT

Bilateral collaborations within the EC

France:
The annual reviews of the five-year Memorandum of Understanding with the French Institut National de la Recherche Agronomique (INRA), signed in 1988, and that between the AFRC Silsoe Research Institute and the Centre National du Machinisme Agricole, du Génie Rural, Des Eaux et des Forêts (CEMAGREF) signed in 1989, show that both are providing important foci for bilateral collaborations. Contacts are also being strengthened with the Centre National de la Recherche Scientifique (CNRS) through meetings and joint discussions.

The first AFRC/INRA Postdoctoral Fellowship awards were advertised in mid-1990. These support longer term visits (6–12 months) and are awarded annually. Successful candidates (4 from the UK and 4 from France) took up their posts between October 1990 and March 1991. In a second round of awards, a further six Fellows were appointed in December 1990.

Within the AFRC/INRA agreement, an annual joint budget of £70K supports a wide range of short (up to two weeks) exchange visits between laboratories in the two countries.

Netherlands:
A five-year Memorandum of Understanding between the AFRC and Dienst Landbouwkundig Onderzoek (DLO) was signed in January 1991. The main scientific priorities for the first two years were identified at a series of joint workshops held in November 1990. They include: food storage and processing, biotechnology in food, plant gene expression, efficient use of nutrients in plants, sustainable agriculture/crop management methods, soil microbiology, animal welfare, vaccinology for control and eradication of animal disease, molecular mechanisms of susceptibility and resistance in viral diseases, peptides and bacterial virulence proteins. These are being taken forward by joint scientific groups led by paired UK and Dutch coordinators. The first review meeting will be held in Swindon in January 1992.

Anglo-Dutch scientific collaboration is being further strengthened through closer links with the Dutch National Research Organisation (NWO).

A small programme to support scientific visits between AFRC and Dutch laboratories for collaborative research projects and the development of proposals for new joint projects funded 35 visits between July 1990 and March 1991.

Germany:
AFRC has collaborated closely with the British Council in the latter's Academic Research Collaboration Scheme with the former Federal Republic. In both 1990 and 1991 AFRC provided a panel of referees in the agricultural and biological sciences. Seven AFRS scientists were among the 59 successful applicants for the 1990/91 round. In March 1991, AFRC participated in a meeting to explore the opportunities for developing research links between the UK and the former Democratic Republic. This meeting was hosted by the British Council, the Berlin Office of the Federal Ministry of Research and Technology and the British Embassy in Bonn.

Between July 1990 and March 1991, a small programme of support provided for 36 short-term exchanges between UK and German scientists in the former Federal Republic.

Spain:
AFRC has continued to enhance research links with leading Spanish laboratories. IAH has established links with the two leading animal health laboratories in Madrid, and several postdoctoral and postgraduate scientists are currently working at IAH. IFR is strengthening links with three national food research laboratories in Madrid, Seville and Valencia, and is developing joint responses to opportunities in food-related research in the Agriculture, and Science and Technology for Developing Countries lines of the Third EC Framework Programme. IPSR has increased its level of cooperation with the universities of Murcia, Seville, Oviedo and Madrid and with the Centro Nacional de Biotechnologia. IACR scientists are strengthening links with the Instituto de Agroquimica y Technologia de Alimentos (Valencia) and the Instituto de Investigaciones Agraris (Valencia).

Eastern Europe and the Soviet Union

In June 1990, AFRC instigated a small scientific interchange scheme (£25K) supporting visits to and from Hungary, Poland, Czechoslovakia, the former Democratic Republic of Germany, the USSR, Bulgaria and Romania. Forty–two visits were supported. Scientists from the Ministries of Agriculture of Czechoslovakia and Poland visited AFRC Central Office in 1990.

Following the 1990 agreement between the British Council's Agriculture and Veterinary Sciences Advisory Committee and the Soviet Academy of Agricultural Sciences (Vaskhnil), scientists from IACR and IGER participated in successful workshops in Leningrad aimed at stimulating closer scientific cooperation.

Dr Brian Jamieson, Director of AFRC Central Office represented the UK Research Councils in a 5-day mission sponsored by the British Council to assess recent developments in higher education in Hungary.

Australia/New Zealand

AFRC is coordinating, on behalf of the Research Councils, a three-year collaboration on biotechnology (1990–1993). The AFRC contribution is £18K ***per annum***. The priority areas for collaboration are: membrane transport; mammalian reproductive biology; targeted insertion and deletion of genes, and gene regulation in plants and viruses; transgenic animals; mapping complex genomes; molecular resistance to disease. A total of 21 exchange visits took place during 1990/91.

EC PROGRAMMES – AFRC INSTITUTE PARTICIPATION,
as at 31 March 1991

ACE (Actions by the Community for the Environment)

- *In situ* decontamination of metal–polluted soils by means of metal–accumulator plants *(IACR)*

BRIDGE (Biotechnology Research for Innovation, Development and Growth in Europe)

- Porcine genome mapping programme (PiGMaP) *(IAPGR)*
- Identification and functional analysis of genes controlling major metabolic pathways in higher plants *(IACR, IPSR)*
- The plasmalemma and the tonoplast of plant cells as targets to increase plant productivity *(IACR)*
- Training network on Seeds of Tomorrow through Genetic Engineering *(IACR, IPSR)*
- Molecular control of genetic instability in regeneration of crop plants *(IACR)*
- Improvement and exploitation of lactic acid bacteria for biotechnology purposes *(IFR)*
- The isolation and characterisation of peptidases from LAB: their role and application in cheese ripening and flavour production *(IFR)*
- Regulation of the inductive phase of microspore embryogenesis *(IPSR)*
- Molecular genetics and physiology of self incompatibility in *Brassica* crops *(IPSR)*
- Development and use of *Arabidopsis thaliana* as a tool for isolating genes of agronomic importance *(IPSR)*
- Molecular analysis of carrot somatic embryogenesis *(IPSR)*
- The molecular biology of cell–to–cell movement of plant viruses in relation to plasmodesmatal function *(IPSR)*
- Integration of primary metabolism, secondary metabolism and differentiation in *Streptomyces coelicolor*: a biochemical, physiological and genetical approach *(IPSR)*
- The molecular and genetic analysis of genes controlling flower development *(IPSR)*
- the molecular analysis of higher plant embryogenesis *(IPSR)*
- Sequence variation in rinderpest strains of widely different pathogenicity *(IAH)*
- The use of molecular techniques in the pathogenesis and persistence of FMDV in livestock and a model cell culture system *(IAH)*
- Rinderpest immunosuppression *(IAH)*
- Community Reference Laboratory *(IAH)*
- Infectious bronchitis virus antigens *(IAH)*

CAMAR (Competitiveness of Agriculture and Management of Agricultural Resources)

- Research into and development of integrated arable farming systems – European network *(IACR)*
- Detection of potato cyst nematodes *(IACR)*

Climatology

- Modelling the effects of climate on crop productivity *(IACR)*

ECLAIR (European Collaborative Linkage of Agriculture and Industry through Research)

- To explore and improve the industrial uses of EC wheats *(IACR, IFR)*
- To increase the use of *Pisum* and other grain legume seeds by improving their quality and nutritional value by genetics and technological transformation *(IFR, IPSR)*
- Systems analysis – Biorefinery *(SRI)*
- Upgrading of straw into strawpaper and polymeric materials *(SRI)*

EPOCH (European Programme on Climatology and natural Hazards)

- Effects of climatic change on agricultural and horticultural potential across the EC *(IACR)*

FLAIR (Food–Linked Agro–Industrial Research)

- Spectroscopic methods for the establishment of food quality *(IFR)*
- Relating sensory, instrumental and consumer choice studies *(IFR)*
- Predictive modelling of microbial growth and survival in food *(IFR)*
- Micronutrient intake, absorption and status *(IFR)*
- Physiological implications of the consumption of resistant starch *(IFR)*
- Improvement of the quality and compatability of food consumption and food composition data in Europe *(IFR)*
- Study of the production and utilisation of fibres with enhanced functional qualities and beneficial nutritional properties *(IFR)*
- Application of oxidoreductase enzymes for food preservation *(IFR)*
- Mechanisms of food intolerance: relationship between gut mucosal integrity, allergy and adverse reactions *(IFR)*
- Development of computer–aided process design procedures to improve quality and safety of products with a limited shelf life *(IFR)*
- Investigation of minimum level of sulphur dioxide required for optimum wine quality *(IFR)*
- New technologies and raw materials for nutritious and attractive cereal products *(IFR)*

SCIENCE (Scientific and technical cooperation)

- Molecular biology and fungally-transmitted viruses of barley *(IACR)*
- Production of insect semiochemicals by genetically-engineered crops *(IACR)*

STEP (Science and Technology for Environmental Protection)

- A unifying concept for the assessment of the bioavailability and leachability of cadmium and zinc *(IACR)*
- Heavy metal toxicity to soil microbes *(IACR)*
- Denitrification and emission from different types of cultivation systems and soil types *(IACR)*

STD (Science and Technology for Development)

- Enhancing national programme research to increase and sustain durum wheat production in Ethiopia *(IACR)*
- Identification and characterisation of proteins and cDNAs that determine insect resistance in cowpea and other grain legumes *(IACR)*
- Integrated methods for the prevention of moulding in farm stored grain *(IACR)*
- Phenolic compounds in maize crop residues affecting nutritive value. Influence of species variety and environment *(IGER)*
- Improving the performance of agricultural vehicles and implements in wet paddy fields *(SRI)*
- Increasing the efficiency of draught animal powered crop production through the development of novel cultivation implements and improved harnessing *(SRI)*
- Studies on calcium absorption and adaptation to low calcium intakes *(IFR)*
- Immunity and genetic resistance to tropical *Theileriosis* *(IAPGR)*
- Technological improvements of tropical cereals – sorghum and maize *(IFR)*

Others

- AFRC institutes also participate in EC twinning grants, stimulation grants and in the Community Bureau of Reference Standards.

Japan

As part of an increased national effort to stimulate Anglo-Japanese science and technology cooperation, AFRC participated in a seminar in Tokyo in November 1990 on the interaction of agriculture with climatic change. Areas for possible future collaborative research were identified. Following the seminar, AFRC representatives toured several laboratories and institutes in Japan.

Scientists at the John Innes Institute have received a major award from the Human Frontier Science Program (HFSP) initiated by the Japanese Government. This award is part of a three-year project costing $600,000 on the genetic control of flower development, being led by Professor Elliot Meyerowitz in Pasadena, USA and Dr Enrico Coen of the John Innes Institute. In addition an HFSP Fellowship has been awarded for a visiting postdoctoral fellow to join the Norwich group.

Three other HFSP Fellowships have been awarded for scientists to visit the AFRC Centre for Genome Research at the University of Edinburgh.

Dr Steve Jarvis of IGER has been awarded Y6 million by the Japanese Research Institute of Innovative Technology for the Earth (RITE). He was the only foreigner among twelve winners of grants.

Collaborations with other developed countries

AFRC participates in two important annual international meetings on the management of scientific R & D – the Tetrapartite meeting of senior representatives of the AFRC, MAFF and SOAFD, the United States Department of Agriculture, Agriculture Canada and INRA; and EURAGRI, the European Agricultural Research Initiative.

The Tetrapartite meeting in Quebec City in May 1990 covered research partnerships, cooperative research with eastern Europe, intellectual property rights, bioethics and food safety. Bilateral links between AFRC and the US National Science Foundation are strong in the field of plant molecular biology, and a top–level meeting is planned for 1991/92.

The EURAGRI meeting in November 1990 covered research on non-food uses of agricultural products, the new EC agricultural research database (AGREP) and the conservation of plant genetic resources.

Developing countries

AFRC has strengthened its links with the Overseas Development Administration and the Natural Resources Institute – the principal UK bodies funding and managing agricultural research in developing countries. Regular liaison and review meetings have been established.

AFRC institute staff continue to provide a wide range of educational, consultancy and research training support, mainly funded by agencies such as ODA, the British Council and organisations of the United Nations. The Overseas Division of the AFRC Silsoe Research Institute is funded principally by ODA. The same body supports Tropical Weeds, Biometrics, and Tropical Viruses Units within IACR.

The following were among the awards received by AFRC institutes during the year under review. IACR Rothamsted was awarded over £200K over three years from NRI to support work on diagnostic techniques for the widespread tropical pathogen *Pseudomonas solanacearum*. The AFRC Silsoe Research Institute was awarded an ODA contract worth £1M for a programme of tractor rehabilitation in Sri Lanka. Similar schemes have been proposed for Nigeria, Tanzania and Uganda. An ODA award of £250K has been made to the Cambridge Laboratory (IPSR) to develop a gene map of millet, in collaboration with breeders and millet geneticists at ICRISAT, India. A three-year award by ODA to IGER will examine "thermal kinetic windows" in tropical maize, and will assess available genetic variation for environmental stress tolerance.

In 1990/91 AFRC project income from the ODA and NRI totalled about £1M.

INTERNATIONAL MEETINGS

AFRC scientists participate in a large number of international scientific symposia and conferences, often as invited lecturers. During the year under review scientists from AFRC institutes contributed to over 300 such meetings, including the following:

- Conference of the European Network of Immunology Institutes, Les Embiez, France - May 1990.
- 8th International Congress on Nitrogen Fixation, Knoxville, Tennessee, USA - May 1990.
- 13th General Meeting, European Grassland Federation, Banska Bystrica, Czechoslovakia - June 1990.
- 4th International Conference on *Arabidopsis*, Vienna,Austria - June 1990.
- 7th International Congress on Plant Tissue and Cell Culture, Amsterdam, Holland - June 1990.
- American Poultry Breeders Round Table, St. Louis, USA - July 1990.
- 5th European Congress of Biotechnology, Copenhagen, Denmark - July 1990.
- XVth International Biometric Conference, Budapest, Hungary - July 1990.
- 200th American Chemical Society National Meeting, Washington DC, USA - August/September 1990.
- IUPAC 7th International Congress of Pesticide Chemistry, Hamburg, Germany - August 1990.
- 4th International Mycological Congress, Regensberg, Germany - August/September 1990.
- International Soil Science Society Congress, Kyoto, Japan - August 1990.
- Australian Society for Reproductive Biology, Perth, Australia - The James Goding Lecture (Dr R M Moor IAPGR) - September 1990.
- 23rd International Dairy Congress, Montreal, Canada - October 1990.
- Pan-American Veterinary Congress, at Valdivia, Chile - October 1990.
- 2nd Congress of the Asian and Oceanian Physiological Societies, New Delhi, India - November 1990.
- Anglo-Japanese Seminar on Agriculture as Applied to Climatic Change, Japan - December 1990.
- Keystone Symposia - The Genetic Dissection of Plant Cell Processes, Keystone, Colorado, USA - January 1991.

ORGANISATION AND HUMAN RESOURCES

The Council's restructuring programme launched in 1985/6 is continuing to run on schedule. The Bristol Laboratory of the AFRC Institute of Food Research (IFR) closed in December 1990. The new building for the Reading Laboratory of IFR is scheduled for occupation in early 1992.

The Cambridge Laboratory (formerly part of the Plant Breeding Institute, Cambridge) transferred to a new laboratory complex at Norwich, the John Innes Centre, and was opened by HRH The Princess Royal in September 1990. The Cambridge Laboratory is part of the AFRC Institute of Plant Science Research.

As part of the continuing programme of disposing of surplus facilities, the farm at Stanhope in the Scottish borders has been sold, and the farm at Cold Norton, Staffordshire, is currently being marketed for sale. Both were part of the surplus land held by the AFRC Institute of Animal Physiology and Genetics Research.

The AFRC Institute of Engineering Research changed its name to the AFRC Silsoe Research Institute with effect from 1 April 1991. The new name is used throughout this Report.

MANAGEMENT BOARD
at 31 March 1991

Professor T L Blundell FRS
Deputy Chairman and Secretary*, AFRC

Professor F J Bourne
Director of Animal Health Research

Professor R B Flavell
Chairman, IPSR Management Committee

Professor D L Georgala CBE
Director of Food Research

Professor R B Heap FRS
Director of Animal Physiology and Genetics Research

Dr B G Jamieson
Director, AFRC Central Office

Professor B J Legg
Director of Engineering Research

Professor T Lewis
Director of Arable Crops Research

Professor J L Stoddart
Director of Grassland and Environmental Research

Assessor

Mr K W Moore
SOAFD

** now Director General*

Personnel

On 31 March 1991, there were 2766 staff employed on permanent appointments and 194 vacancies in the institutes of the AFRC. Of these posts, 1554 were in the Science Group, of which 1443 were at graduate or equivalent levels. The balance of staff are mainly in the P&TO Group, the Administration Group and support staff. There were also 613 short term posts, principally in the Science Group, 252 of which were AFRC–funded and 361 funded by industry and other sources. The number of permanent staff in the AFRC Central Office, including the Computing Division at Harpenden, was 198. The Central Office complement at Swindon was 150 or 4% of the numbers employed in AFRC.

The above figures ***exclude*** AFRC employees seconded to Horticulture Research International, formerly the AFRC Institute of Horticultural Research.

Comparative staffing figures for the 10 year period to 1990/91 show some interesting trends. As Figure 1 illustrates, short–term appointments were not a feature of AFRC employment in 1981. These accounted for 15% of the Science Group complement by 1986. Today, they represent some 25% of AFRC Science Group posts, and this proportion is set to rise to 27% by 1994/95.

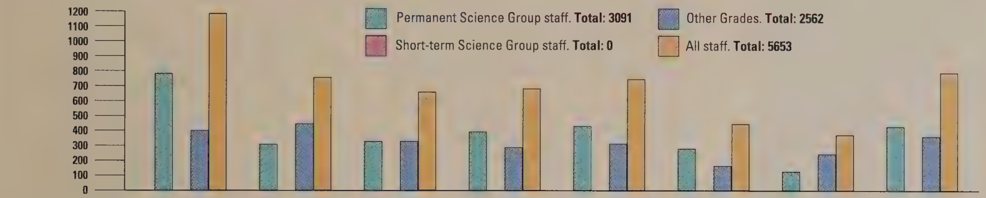
One of the objectives of AFRC's restructuring has been to ensure that as large a proportion of the overall budget as possible is available for scientific research. In staffing terms, in 1981, 55% of AFRC staff were in the Science Group. The position has improved so that by 1991, the figure has risen to 58%, despite major cuts in the AFRC's research programme and the loss of some 1600 permanent science posts.

Figure 2 shows overall AFRC staffing projections for the period to 1994/95. Modest reductions in the permanent complement are predicted, due largely to restructuring, with increases in the numbers of short–term posts. At the same time, additional financial support for HEIs has increased the numbers of scientific and technical staff *indirectly* supported by AFRC funds from 430 in 1988/89 to 800 in 1990/91. This figure is set to rise to 940 by 1994/95, by which time some 67% of staff supported by AFRC will be in the Science Group or equivalent HEI grades.

The numbers of visiting scientists working at AFRC institutes during 1990/91 is shown in Figure 3.

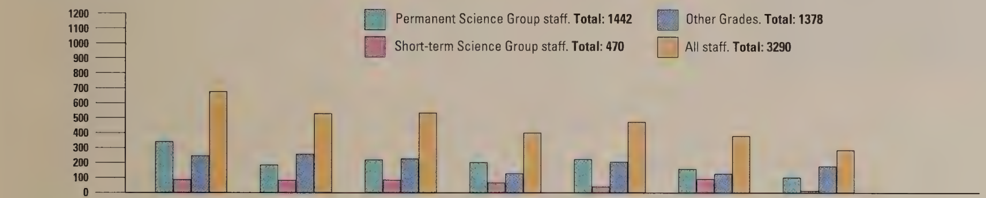
Figure 1: Staff in post in AFRC Institutes

A: 1 April 1981



Institute	IACR	IAH	IAPGR	IFR	IGER	IPSR	SRI	HRI*	
Science Group staff as % of total	66%	41%	50%	58%	58%	63%	34%	54%	**Total: 55%**

B: 1 April 1991



Institute	IACR	IAH	IAPGR	IFR	IGER	IPSR	SRI	HRI*	
Science Group staff as % of total	64%	51%	58%	68%	56%	66%	38%	-%	**Total: 58%**

**Transferred to MAFF from 1 April 1991*

Figure 2: AFRC Human Resource Projections to 1994/95

These projections include AFRC Central Office, vacancies and HEI posts supported by AFRC Research Grants. Thus, they are not directly comparable with Figure 1.

CATEGORY	YEAR							
	1991/92 (Actuals)		*1992/93*		*1993/94*		*1994/95*	
Science Group		%		%		%		%
Permanent	1570		1490		1490		1490	
Short-term	544		530		555		555	
HEI	840		900		900		940	
SUB-TOTAL	2954	64	2920	66	2945	66	2985	67
Other Grades	1656		1495		1495		1495	
TOTAL	***4610***		***4415***		***4440***		***4480***	

Figure 3: Visiting Scientists at AFRC Institutes in 1990/91

Institute	IACR	IAH	IAPGR	IFR	IGER	IPSR	SRI	TOTAL
Number	74	28	97	34	13	45	11	***302***

Continuing financial difficulties, including the final tranche of the MAFF "near market" commission expenditure cuts, effective from 1991/92, resulted in a net loss of 300 permanent posts in 1990/91. Gross losses were off–set to some extent by new permanent posts in high–priority research areas and by increased external funding of short–term posts.

New career development arrangements for staff of exceptional ability and potential were agreed during the period covered by this Report. The AFRC Staff Reporting and Appraisal procedures were modified, to provide for fully open reporting and better feed–back on objectives and performance. In addition, negotiations took place with the Trade Unions leading to a new Redundancy Agreement, which takes more account of the wishes of individuals and eliminates much of the bureaucracy inherent in the original agreement.

AFRC became the first Research Council to take part in the Look After Your Heart campaign.

AFRC SENIOR STAFF

Professor T L Blundell FRS
Deputy Chairman and Director General

Dr B G Jamieson
Director of Administration

Dr A V Harrison
Head of Policy Division

Mr R J Price
Chief Personnel Officer

Mr S H Visscher
Chief Finance Officer

Dr J N Wingfield
Acting Head of Science Division

The following staff changes have taken place:

SECRETARY

Professor T L Blundell FRS was appointed to the post of Secretary with effect from 1 January 1991 following the resignation of *Professor W D P Stewart FRS*.

CHANGES IN DIRECTORSHIP

AFRC Institute of Plant Science Research

Professor H W Woolhouse resigned as Director of Plant Science Research with effect from 18 May 1990. *Professor R B Flavell* has been appointed Chairman of the IPSR Management Committee, and IPSR representative on AFRC Management Board.

AFRC Silsoe Research Institute

Professor B J Legg was appointed Director of Engineering Research with effect from 1 August 1990, following the retirement of *Professor J Matthews CBE*.

SENIOR STAFF CHANGES

AFRC Central Office

Dr J N Wingfield was appointed Acting Head of Science Division with effect from 1 August 1990 following the resignation of *Dr J V Lake* on 31 July 1990.

Mr R J Price was appointed Chief Personnel Officer with effect from 5 April 1991 in succession to *Mr J M Y Dickens* who retired on 4 April 1991.

AFRC Institute of Arable Crops Research

Dr R T Plumb was appointed Head of Crop Protection Division with effect from 17 December 1990.

AFRC Silsoe Research Institute

Dr W Henderson was appointed Deputy Director and Head of Business Development with effect from 19 September 1990.

INDIVIDUAL MERIT PROMOTIONS

The following members of AFRC staff were awarded Individual Merit Promotion in 1990/91 to Grade 6 with effect from 1 July 1990:–

Drs G Leng, D B Sattelle and *R J Bicknell*, AFRC Institute of Animal Physiology and Genetics Research, Cambridge Research Station.

Dr R L Spooner, AFRC Institute of Animal Physiology and Genetics Research, Edinburgh Research Station.

Dr A L Devonshire, AFRC Institute of Arable Crops Research, Rothamsted Experimental Station.

Dr J W Snape, Cambridge Laboratory, AFRC Institute of Plant Science Research.

Drs J A Downie and *C W Lloyd*, John Innes Institute, AFRC Institute of Plant Science Research.

HONOURS AND AWARDS

Birthday Honours

OBE: Dr M E Rose, AFRC Institute for Animal Health, Houghton Laboratory.

BEM: Mr P W Dalley, Storeman, AFRC Silsoe Research Institute.

BEM: Mr J G Wink, former Head Gardener, AFRC Institute of Food Research, Norwich Laboratory.

New Year Honours

MBE: Mrs J M Faulkner, Horticulture Research International.

OTHER DISTINCTIONS

Dr G Bulfield, AFRC Institute of Animal Physiology and Genetics Research, Edinburgh Research Station, was awarded an Honorary Professorship in Agriculture and Genetics by the University of Edinburgh.

Dr D C Clark, AFRC Institute of Food Research, was awarded the 1990 Royal Society of Chemistry's Food Chemistry Group Junior Medal.

Dr R R Davenport, AFRC Institute of Food Research, was awarded Honorary Associateship of the International Mycology Institute, Kew.

Dr B J Legg, AFRC Silsoe Research Institute, was appointed a Visiting Professor by the Cranfield Institute of Technology.

Dr C R Martin, John Innes Institute, AFRC Institute of Plant Science Research, was awarded a President's Medal by the Society for Experimental Biology.

Dr W I Morrison, AFRC Institute for Animal Health, Compton Laboratory, received the Pfizer Award from the World Association of Buiatrics.

Professor D A T Southgate, AFRC Institute of Food Research, was awarded the 1990 Royal Society of Chemistry's Food Chemistry Group Senior Medal.

Council Strategy Committee *at 31 March 1991*

Chairman

Professor T L Blundell FRS
Deputy Chairman and Secretary, AFRC

Members

Professor E C D Cocking FRS
University of Nottingham

Dr B G Jamieson
Director, AFRC Central Office

Professor J R Krebs FRS
University of Oxford

Professor H Smith FRS
Royal Society Assessor

Professor R Whittenbury
University of Warwick

Council Development Committee *at 31 March 1991*

Chairman

Mr D F R George
Dyfed Seeds

Members

Professor T L Blundell FRS
Deputy Chairman and Secretary, AFRC

Professor F J Bourne
Director of Animal Health Research

Professor J M M Cunningham CBE
Formerly West of Scotland College of Agriculture

Mr A H Duberley
Chairman, Finance & General Purposes Committee, Country Landowners Association

Dr B G Jamieson
Director, AFRC Central Office

Mr P Powis
Adviser, Phillips Brown Public Sector

Mr G T Pryce
Chairman, Horticulture Research International and Solway Foods Ltd

Mr B A Staples
Head of Buildings and Supplies Branch, AFRC Central Office

Professor J L Stoddart
Director of Grassland and Environmental Research

Mr S H Visscher
Chief Finance Officer, AFRC

Dr J N Wingfield
Acting Head of Science Division, AFRC Central Office

Membership of the Research Committees *at 31 March 1991*

Animals Research Committee

Chairman

Professor J R Krebs FRS
University of Oxford

Members

Professor I D Aitken
Director, Moredun Research Institute

Professor F J Bourne
Director of Animal Health

Dr M J Evans
University of Cambridge

Professor N T Gorman
University of Glasgow

Professor R B Heap FRS
Director of Animal Physiology and Genetics Research

Professor W F H Jarrett FRS
University of Glasgow

Dr D McE Jenkinson
SOAFD

Dr E B Keverne
University of Cambridge

Professor B J Legg
Director of Engineering Research

Professor M Peaker
Director, Hannah Research Institute

Professor R J Roberts
University of Stirling

Dr D W F Shannon
Chief Scientist, Agriculture and Horticulture, MAFF

Professor H Smith FRS
University of Birmingham

Professor J L Stoddart
Director of Grassland and Environmental Research

Mr S P Vranch
Celltech Group plc

Professor D Wakelin
University of Nottingham

Dr M Wallis
University of Sussex

Dr J N Wingfield
Acting Head of Science Division, AFRC Central Office

Food Research Committee

Chairman

Professor R Whittenbury
University of Warwick

Members

Professor J P Arbuthnott
University of Nottingham

Professor E D T Atkins
University of Bristol

Professor G G Dodson
University of York

Dr S Dyer
MRC

Dr D B Gammack
Consultant

Professor D L Georgala CBE
Director of Food Research

Mr G E G Harvey
Marks and Spencer plc

Professor R M Hicks
United Biscuits UK Ltd

Professor W P T James
Director, Rowett Research Institute

Dr D McE Jenkinson
SOAFD

Dr M E Knowles
Chief Scientist, Fisheries and Food, MAFF

Professor B J Legg
Director of Engineering Research

Professor P J Lillford
Unilever Research

Professor C Ratledge
University of Hull

Dr J N Wingfield
Acting Head of Science Division, AFRC Central Office

Plants and Environment Research Committee

Chairman

Professor E C D Cocking FRS
University of Nottingham

Members

Professor D Boulter CBE
University of Durham

Dr J T Braunholtz
Horticultural Development Council

Dr R J Dowdell
SOAFD

Professor R B Flavell
Chairman, IPSR Management Committee

Professor P T Haskell CMG
University of Wales

Professor J R Hillman
Director, Scottish Crop Research Institute

Professor B J Legg
Director of Engineering Research

Professor T Lewis
Director of Arable Crops Research

Professor T A Mansfield FRS
University of Lancaster

Dr C C Payne
Horticulture Research International

Professor J A Raven FRS
University of Dundee

Professor G R Stewart
University College, London

Professor J L Stoddart
Director of Grassland and Environmental Research

Professor J K Syers
University of Newcastle–upon–Tyne

Professor M H Unsworth
University of Nottingham

Dr D J White
MAFF

Dr J N Wingfield
Acting Head of Science Division, AFRC Central Office

Engineering Advisory Group

Chairman

Vacant

Members

Professor B G Batchelor
University of Wales

Dr R J Dowdell
SOAFD

Professor B J Legg
Director of Engineering Research

Professor J R O'Callaghan
University of Newcastle–upon–Tyne

Mr E C Pape
Consultant

Professor D L Pyle
University of Reading

Mr S P Vranch
Celltech Group plc

Dr D J White
MAFF

Mr J W G Young
P J Parmiter & Sons Ltd

Membership of the Research Grants Boards *at 31 March 1991*

Animals Research Grants Board

Chairman

Professor W F H Jarrett FRS
University of Glasgow

Members

Professor J P Arbuthnott
University of Nottingham

Professor P J Buttery
University of Nottingham

Dr L R Fraser
King's College, London

Dr H J Gilbert
University of Newcastle–upon–Tyne

Professor W G Hill FRS
University of Edinburgh

Dr D F Houlihan
University of Aberdeen

Professor I McConnell
University of Edinburgh

Professor W Mordue
University of Aberdeen

Professor D Onions
University of Glasgow

Professor B T Pickering
University of Bristol

Dr E Simpson
Clinical Research Centre
Northwick Park Hospital

Professor A J F Webster
University of Bristol

Food Research Grants Board

Chairman

Professor C Ratledge
University of Hull

Members

Dr A C Baird–Parker
Unilever Research

Professor J M V Blanshard
University of Nottingham

Professor C Bucke
Polytechnic of Central London

Dr J H Cummings
MRC Dunn Clinical Nutrition Centre

Dr A M Donald
University of Cambridge

Dr P J Frazier
Dalgety plc

Professor A Godfrey
Biocatalysts Ltd

Professor C F Higgins
University of Oxford Institute of Molecular Medicine

Dr J Mann
Amersham International plc

Professor A W Nienow
University of Birmingham

Professor D S Robinson
University of Leeds

Dr J Wardle
Institute of Psychiatry

Plants and Environment Research Grants Board

Chairman

Professor G R Stewart
University College, London

Members

Dr S W J Bright
ICI International Seeds Business

Professor J A Callow
University of Birmingham

Professor H G Dickinson
University of Reading *(From 1 October 1991: University of Oxford)*

Dr J Draper
University of Leicester

Professor D Grierson
University of Nottingham

Dr P J Grubb
University of Cambridge

Dr C N Hunter
University of Sheffield

Dr D S Ingram
Royal Botanic Garden, Edinburgh

Professor D L Lee
University of Leeds

Professor R M Leech
University of York

Professor S P Long
University of Essex

Professor J R O'Callaghan
University of Newcastle–upon–Tyne

Professor J K Syers
University of Newcastle–upon–Tyne

Professor M H Unsworth
University of Nottingham

Dr A Vivian
Bristol Polytechnic

Professor A E Walsby
University of Bristol

AFRC Institutes

AFRC Institute for Animal Health (IAH)
Compton
Near Newbury
Berkshire RG16 0NN
Telephone: (0635) 578411
Director: *Professor F J Bourne*

AFRC Institute of Animal Physiology and Genetics Research (IAPGR)
Babraham Hall
Babraham
Cambridge CB2 4AT
Telephone: (0223) 832312
Director: *Professor R B Heap FRS*

AFRC Institute of Arable Crops Research (IACR)
Harpenden
Herts AL5 2JQ
Telephone: (0582) 763133
Director: *Professor T Lewis*

AFRC Institute of Food Research (IFR)
Shinfield
Reading RG2 9AT
Telephone: (0734) 884530
Director: *Professor D L Georgala CBE*

From January 1992 –
Earley Gate
Whiteknights Road
Reading RG6 2EF

AFRC Institute of Grassland and Environmental Research (IGER)
Plas Gogerddan
Aberystwyth
Dyfed SY23 3EB
Telephone: (0970) 828255
Director: *Professor J L Stoddart*

AFRC Institute of Plant Science Research (IPSR)
John Innes Centre
Norwich Research Park
Colney
Norwich NR4 7UH
Telephone: (0603) 52571
Chairman, IPSR Management Committee:
Professor R B Flavell

AFRC Silsoe Research Institute (SRI)
Wrest Park
Silsoe
Bedford MK45 4HS
Telephone: (0525) 60000
Director: *Professor B J Legg*

Scottish Agricultural Research Institutes

These institutes, together with the AFRC institutes, make up the Agricultural and Food Research Service. They are funded by The Scottish Office Agriculture and Fisheries Department and are not reported on in detail here.

Hannah Research Institute (HRI)
Ayr KA6 5HL
Telephone: (0292) 76013/7
Director: *Professor M Peaker*

Macaulay Land Use Research Institute (MLURI)
Craigiebuckler
Aberdeen AB9 2QJ
Telephone: (0224) 318611
Director: *Professor T J Maxwell*

Moredun Research Institute (MRI)
408 Gilmerton Road
Edinburgh EH17 7JH
Telephone: (031) 664 3262
Director: *Professor I D Aitken*

Rowett Research Institute (RRI)
Greenburn Road
Bucksburn
Aberdeen AB2 9SB
Telephone: (0224) 712751
Director: *Professor W P T James*

Scottish Crop Research Institute (SCRI)
Invergowrie
Dundee DD2 5DA
Telephone: (0382) 562731
Director: *Professor J R Hillman*

Acronyms

ABA Abscisic acid
ADAS Agricultural Development and Advisory Service
AFRC Agricultural and Food Research Council
AFRS Agricultural and Food ResearchService
AHS African horse sickness

BLG ß–lactoglobulin
BSE Bovine Spongiform Encephalopathy
BRIDGE Biotechnology Research for Innovation, Development and Growth in Europe
BTV Bluetongue virus

CEMAGREF Centre National du Machinisme Agricole du Génie Rural des Eaux et des Forêts
CGR Centre for Genome Research
CNRS Centre National de la Recherche Scientifique

DANI Department of Agriculture for Northern Ireland
DES Department of Education and Science
DIA Differentiation Inhibition Activity
DLO Dienst Landbouwkundig Onderzoek
DNA Deoxyribonucleic acid
DTI Department of Trade and Industry

EAE Enzootic abortion of ewes
EC European Community
ECLAIR European Collaborative Linkage of Agriculture and Industry through Research
ELISA Enzyme–Linked Immunosorbent Assay
EPOCH European Programme on Climatology and natural Hazards
ESRC Economic and Social Research Council
EURAGRI European Agricultural Research Initiative

GER Global Environmental Research
GH Growth hormone

HEI Higher Education Institution
HFSP Human Frontier Science Program
HSP Heat–shock proteins

ICRISAT International Crops Research Institute for the Semi–Arid Tropics
INRA Institut National de la Recherche Agronomique

MAFF Ministry of Agriculture, Fisheries and Food
MHC Major Histocompatibility Complex
MRC Medical Research Council

NERC Natural Environment Research Council
NRI Natural Resources Institute

ODA Overseas Development Administration

PCR Polymerase chain reaction
PMT Putrescine methyl transferase

QTL Quantitative trait loci

RNA Ribonucleic acid
rRNA Ribosomal ribonucleic acid

SAF Scrapie Associated Fibrils
SERC Science and Engineering Research Council
SOAFD Scottish Office Agriculture and Fisheries Department

AGRICULTURAL AND
FOOD RESEARCH COUNCIL

Polaris House, North Star Avenue,
Swindon SN2 1UH

Telephone *(0793) 413200*